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THE UNIVERSITY OF ALBERTA
A GEOCHEMICAL SURVEY AND THE NATURE OF LEAD-SILVER
ORES IN THE SIXTYMILE RIVER AREA, YUKON TERRITORY.

by

(C)

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A THESIS
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled A Geochemical Survey and the Nature of Lead-Silver Ores in the Sixtymile River Area, Yukon Territory, submitted by Michael S. Cholach, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

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27

ABSTRACT

This study involves geochemical and mineralogical investigations of Pb-Ag vein-ore deposits in the Sixtymile River District, Yukon Territory. The geochemical investigations comprised a geochemical-prospecting orientation survey using ammonium citrate-HCl extracts of residual soil samples analyzed for Ag, Cu, Pb and Zn by atomic absorption spectrometry. Pb was found to be the most suitable element for geochemical prospecting since its weathering from the veins produced superadjacent anomalies of high contrast. The Pb anomalies were distorted down-slope by soil creep and solifluction, but this served simply to increase the areal extent of the anomaly and actually enhance its detectability. The soil leach methods for Pb should be a very effective method of prospecting for Pb-Ag vein mineralization when employed on traverses perpendicular to the strike of the veins with a 50 foot sampling interval.

The vein-type deposits contain hypogene ores with galena as the principle component. Minor chalcopyrite and quartz accompany the galena. Supergene alteration has resulted in the formation of extensive anglesite deposits near surface. Small, but significant concentrations of Ag-rich tennantite (binnite) and covellite occur within the supergene anglesite adjacent to the primary galena. Semi-quantitative electron microprobe analyses of the ores reveal that the principle concentration of silver is within the supergene minerals binnite and covellite, rather than within the primary galena. A study of the clay-gouges within the veins near the surface shows illite to be the principle component.

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INTRODUCTION

Lead-silver ore occurrences have been found within the region known as the Klondike Plateau, adjacent to the International Boundary between the Yukon and Alaska, some 40 miles west of Dawson City, Yukon Territory.

LOCATION

The claims held or under option by Connaught Mines Ltd. in 1959 lie to the south of the Sixtymile River and Boucher Creek (Fig. 31). This area is bounded by the following degrees of latitude and longitude: namely from 63° 53' north to 63° 57' north latitude and 140° 35' west to 140° 55' west. The area is approximately 40 miles due west of Dawson City, Yukon, or 65 miles by road from that settlement.

Existing roads terminate some 5 miles south of the property and access to the base camp, over this latter 5 mile distance, is possible only by foot or by tracked vehicles. From the base camp, the three occurrences of lead-silver ore are again accessible by conventional vehicles.

VEGETATION

The Sixtymile area is only sparsely forested and the tree-line is situated approximately 3500 feet above sea level. Above the 3500 foot level only grasses and a few dwarf birch are found. Below the 3500 foot level, spruce is the most common tree growing at all elevations up to the timberline. Several varieties of poplar are found; these occur on the lower slopes along the valley flats. Shrubs in the area are mostly willow and birch.

The climate in this region is severe with temperatures ranging from -80°F during the winter, to summer highs of 90°F . The summers are short and warm with almost continuous daylight during May, June and July.

The annual precipitation is approximately 11 inches. A relatively large portion of the total precipitation occurs during the spring and fall seasons. Snowfall in the area is moderate and usually commences about mid-September or early October.

TOPOGRAPHY

The property held by Connaught Mines Ltd., is part of that physiographic feature known as the Yukon Plateau. The terrain is a northern member of the series of plateaus and mountain ranges which stretch through British Columbia, the Yukon and Alaska to the Bering Sea. The Yukon Plateau extends north from a latitude of 59° through the central Yukon and Alaska, and is flanked on one side by the mountains of the Coast System, and on the other side by ranges of the Rocky Mountain System and the Brooks Range.

This region was believed to have been extensively planated over a long period of crustal stability and essentially reduced to a slightly undulating plane. The period of stability was terminated by an uplift which resulted in the rejuvenation of streams and subsequent incising of channels in the upland surface. These stream channels have cut deep depressions which vary from 1500 to 4000 feet in depth, giving the region a very irregular topography.

The upland portions near the larger valleys are maturely dissected

and little of the original planar surface remains; however, further back from the main depressions, the original planar-like surface remains at a general elevation of 4000 to 4500 feet with occasional peaks which rise above the plateau surface (Cockfield, 1921).

The amount of uplift which took place is not exactly known and the figures quoted are from earlier geological reports. The evidence available indicates the uplift was the greatest along the margins and least in the centre of the plateau (Brooks, 1906). The plateau has the shape of a wide shallow trough with an axial line corresponding closely to the Lewes and Yukon Rivers. From the axial line, the surface of the plateau slopes upward to the Coast Ranges on the west and to the Rockies on the east. Along the Coast Range, Cairnes (1912) believed that uplift along the flanks may have ranged from 4700 to 5200 feet. Thus, in the Sixtymile region, which lies near the axial line of the trough, uplift may have ranged from 3000 to 4100 feet (Cockfield, 1921). This would indicate that the original surface in the Sixtymile area was approximately 1100 feet above sea level.

The absence of glaciation in this region is indicated by the lack of glacial deposits and is further substantiated by other features such as steep-walled "V"-shaped valleys and the absence of any smoothing or scouring action along the valley walls characteristic of glaciated regions.

The Sixtymile River valley is approximately one mile wide, having gentle slopes, with indications of a former "V"-shaped outline. The smaller creeks have relatively steep walls and are "V"-shaped in outline with narrow bottoms. As a rule, the northern bank of the stream is much steeper than the southern bank due to the sun's action in re-

moving permafrost to a greater extent on these slopes during the summer months and causing greater erosional action due to thawing and freezing.

On the southern slopes of hills and valleys, particularly below the tree-line, permafrost occurs very close to the ground surface. Fig. 1 shows a series of stepped trails, affected by permafrost thawing, leading to the Connaught Mines base camp. These trails were made during the summer of 1968.

Furthermore, where permafrost is present in the substratum it hinders the percolation of water from the thawed ground in the summer and thus creates conditions of saturated earth flow during the warm summer season (Troll, 1958). These conditions have been observed by the writer to the northeast of the No. 3 vein fault. Trees appear to be flowing on the permafrost down a steep valley.



Figure 1. Permafrost conditions on the southern slopes of a hill below the tree-line; Trail to Connaught Mines Ltd. base camp, 1968.

On the higher slopes above the timber-line, the bedrock is almost

entirely covered by a thin veneer of residual soil which varies in thickness from 2 to 12 feet. Frost is the dominant erosive force on the upper slopes and large fragments of bedrock have been brought to the surface by processes of solifluction, giving the ground a patterned appearance as indicated on Fig. 2. Fig. 3 illustrates how percolating ground water has penetrated and broken up the surface of the bedrock by a process of alternate freezing and thawing.



Figure 2. View north from the No. 1 vein towards the No. 2 vein which occurs in the vicinity of the "Caterpillar" tractor removing overburden below. Several well defined stone rings are visible in the foreground.

With reference to Fig. 3, it is in the vicinity of these stone rings that galena float material is sometimes found at surface. It was the discovery of such float material that led to the subsequent exploration.



Figure 3. Bedrock broken up by alternate freezing and thawing of ground water. No. 3 vein.

THE GENERAL GEOLOGIC HISTORY OF THE SIXTYMILE RIVER AREA

INTRODUCTION

The area first became of economic interest in 1892 when placer gold was discovered in the Fortymile Creek district and shortly thereafter gold was discovered in Miller Creek, Bedrock Creek and the Sixtymile River (Fig. 7). Later, during the same summer, further gold discoveries were made in Glacier Creek and Big Gold Creek. The area was worked from 1894 to 1896, when production tapered off with the discovery of gold in the Klondike area. From 1896, gold production decreased steadily, except for a brief period between 1915 and 1916 when the most favorable creeks were dredged.

At the present time several small placer operations are being attempted on some of the creeks flowing into the Sixtymile River. An old dredge is still in place at the junction of Glacier Creek and the Sixtymile River, approximately 7 miles northeast of the Connaught Mines base camp.

In the immediate vicinity of the Sixtymile River, concentrations of galena with some silver values have been known since the 1890's. Some prospecting was done on the higher ridges in an attempt to locate the source of the placer gold. Most of these early attempts at prospecting made little effort to discover lead or silver deposits, as the prospectors were primarily interested in trying to find quartz veins which they felt would lead to a "mother lode" of gold.

Another reason for a relatively limited amount of prospecting done in the higher areas was the lack of rock outcrops. As mentioned in the previous section the depth of overburden ranges from 2 to 12

feet and the overburden consists of fairly large boulders interspersed with small amounts of clay and gravel, through which it is extremely difficult to dig. The presence of permafrost which may be close to the surface has further hindered prospecting.

Early geological reports noted galena carrying silver values to the area south of the Sixtymile River. An early reconnaissance report dating from the early 1900's indicated the presence of rock types which would be favourable for lead-silver mineralization and specifically noted this particular area and the United Keno Hill area as favourable prospecting areas. The latter area is now one of the major producers of lead-silver ore in Canada.

PRELIMINARY EXPLORATION

Previous reports in the files of Connaught Mines Ltd. indicate that prospecting has been done during the past 9 to 10 summer seasons south of the Sixtymile River. However, only during the past four summer seasons has any extensive exploration been carried out. Two prospectors first investigated the presence of galena float in the area and established that this float material follows very definite linear structures which were easily traceable on aerial photographs.

Initial stripping of overburden in these lineaments disclosed several high-grade narrow lead-silver veins within fault zones, one of which was 75 feet long and 12 to 14 inches in width. At this stage the staking of claims was initiated to cover the favourable areas. This occurrence is now referred to as the No. 1 vein (Fig. 31).

DISCOVERY

The three known occurrences of lead-silver ore are located on

the CCI Claim No. 8, the Ben Claim No. 4, and the Jack Claims, Nos. 1 and 2. The location of these occurrences are illustrated in Fig. 31.

The following is a brief description of the exploration which lead to the discovery of these three occurrences. During 1965 and 1966 exploration was carried out by Tottrup and Associates Limited. No further work was done during 1967; however, exploration was resumed in 1968 by Connaught Mines Ltd.

No. 1 vein: In 1965 this vein was exposed over a strike length of 75 feet. At its widest point the vein was 14 inches in width and tapered off to 3 inches in width at either end. During 1966, further stripping was performed and the vein exposed over a strike length of some 200 feet having an average width of 12 to 14 inches. In 1968 exploration was resumed by Connaught Mines Ltd. At this time heavier equipment was used in the stripping operations. As a result, the same vein was then exposed over a strike length of 513 feet having a maximum width of 2.5 feet.

No. 2 vein: During the summer of 1965, a trench was cut at approximately right angles to a strong lineament striking towards north 45° east. At this time it was reported that the trench filled with water due to heavy rains and the exposed rock could not be examined.

In the following year the trench was examined and only minor amounts of galena were found which were attributed to a small lead-silver veinlet and no further exploration was done. However, in 1968 on the advice of R. D. Morton, further trenching was done at this locality and a highly oxidized zone containing traces of galena and

anglesite was uncovered over a strike length of 300 feet. On the eastern exposure of this vein, massive galena and anglesite were uncovered over a width of 1.2 feet. The presence of weathered vein material on either side of the vein indicates that the vein could attain a much greater width with depth. Fig. 4 shows the first indications of the type of ore uncovered before the massive galena was reached.



Figure 4. Typical oxidized ore found above the massive ore of the No. 2 vein.

No. 3 vein: During the summer of 1965, three pits were opened up in the vicinity of this vein. In one of these pits a thin veinlet of galena and anglesite varying in width from 2 to 5 inches was observed. In 1966 further trenching was done which exposed the same vein for 60 feet along strike, the vein varied in width from 1.5 to 4 feet. At this time a bulk sample of the ore from the Numbers 1 and 3 vein faults was combined and shipped to Cominco Ltd. of Trail, British Columbia.



Figure 5. Pit No. 3 vein, showing foot and hanging walls. This is the location of the original sample shipment of 1966.

This ore yielded lead-silver values in the ratio of 1:1.

Work was resumed at this location in 1968 and further trenching exposed the vein over a length of 80 feet. Additional trenching was done along strike of the vein some 300 feet to the northeast. At this point galena was again encountered over a strike length of 60 feet. At both exposures the average width of the vein was 3.5 feet (Fig. 5).

GEOLOGIC AND TECTONIC SETTING

INTRODUCTION

Since geologic mapping in the Yukon and Alaska was commenced, certain rock types have been referred to as belonging to the Precambrian. Although the geology is not fully understood, recent work has substantiated a Precambrian age for some lithological groups and has suggested younger ages for other groups. There are still numerous horizons in the Yukon and Alaska which have been referred to as Precambrian but which have as yet not been proven or disproven.

PRECAMBRIAN ROCKS

The oldest rocks in the Yukon and Alaska are those referred to as the Tindir Group. They occur in the Yukon-Porcupine area along the International Boundary. The type locality was first described by Cairnes (1912) north of Eagle (Fig. 6) in the valley of the Tatonduck River.

The Tindir Group in Alaska has been described by Mertie (1937). The group consists of a thick sequence of unmetamorphosed sedimentary rocks interbedded with basic lava flows and intruded by masses of greenstone. The rocks consist of quartzites, shale, limestones and dolomites. Across the boundary in the Yukon, the Tindir Group consists of slightly metamorphosed quartzites, shales, slates, phyllites and some greenstones. L. Green (1961) recognized this sequence in the Dawson map area as (1) carbonate unit, (2) phyllite unit, (3) grit unit, and (4) schist unit.

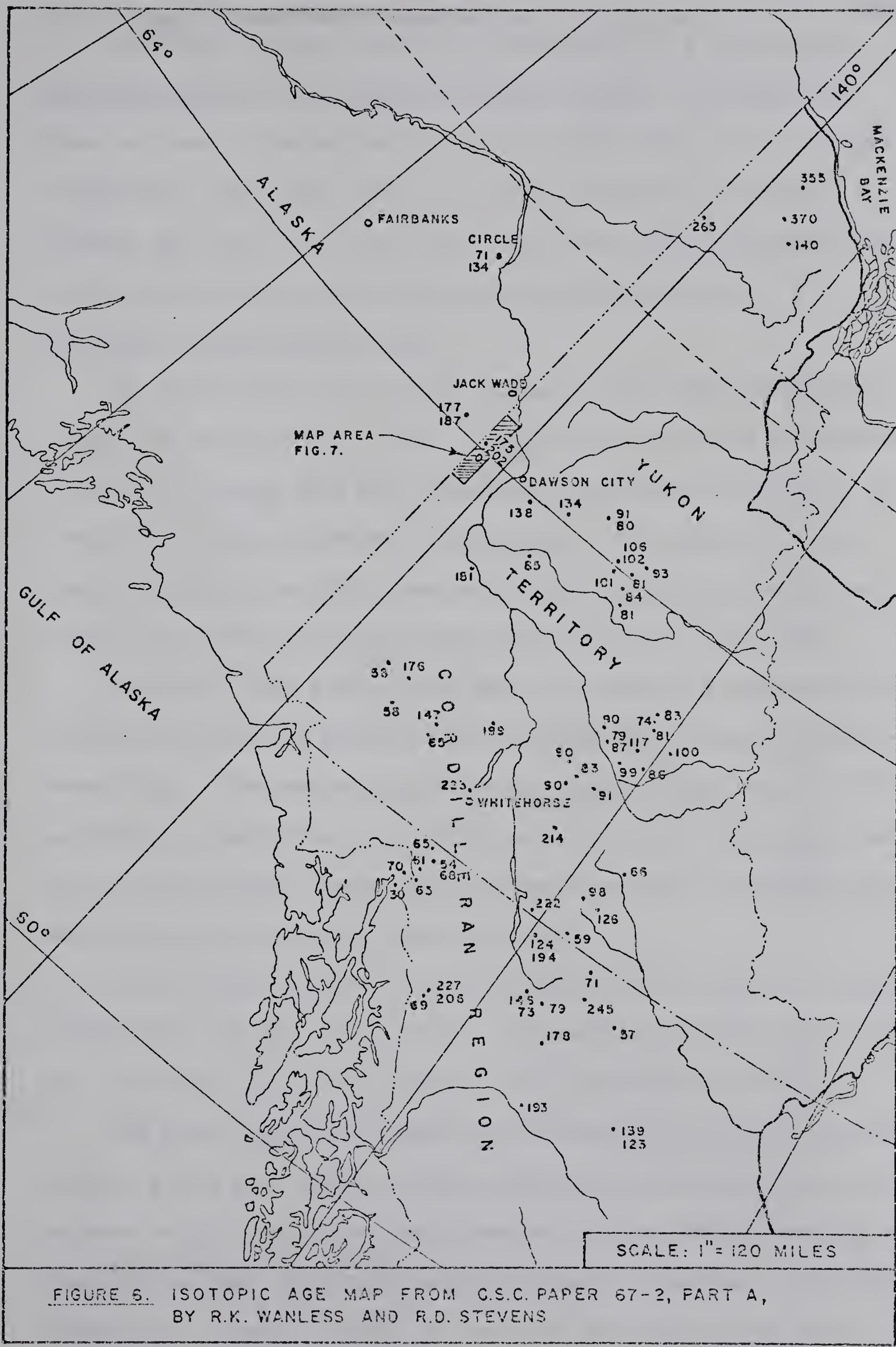


FIGURE 6. ISOTOPIC AGE MAP FROM C.S.C. PAPER 67-2, PART A,
BY R.K. WANLESS AND R.D. STEVENS

The Tindir Group is overlain unconformably by a fossiliferous (Archaeocyathus) Lower Cambrian sequence of rocks. Although this does not prove a Precambrian age for the Tindir Group it is strongly suggestive of one. This group of rocks is found only north of the Tintina fault and lies roughly in a belt along the Yukon-Alaska border in the western Ogilvie Mountains and in the Keeles Range.

PALEOZOIC AND PRECAMBRIAN ROCKS

The Birch Creek schist which occurs near the Circle district in Alaska was named by Spurr (1896). Spurr dated the schist as Precambrian since at that early date all crystalline schists were believed to be Precambrian unless otherwise distinguished. This belief in a Precambrian age for the Birch Creek schist was continued by Mertie and Prindle who worked the Yukon-Tanana Upland area at a later date.

The Birch Creek schist forms about one fifth of the bedrock surface between the Yukon and Tanana rivers in Alaska and outcrops in three known areas. The area which will be discussed in some detail is that in which the lead-silver ore occurrences are found. This is the eastern part of Yukon-Tanana region which continues eastward beyond the international boundary into the Yukon Territory.

In the Yukon Territory Canadian geologists have applied the name "Yukon Group" to the same schists. The Canadian geologists who carried out this early mapping were Cairnes (1912) and Cockfield (1921).

The Birch Creek schist consists principally of quartzite, quartzite schist, quartz mica schist, a minor portion of carbonaceous and calcareous schist, and crystalline limestone (Mertie, 1937); (most of the rocks having been completely recrystallized). In general these lithologies are strongly foliated or laminated and many of them show a

distorted foliation indicative of more than one phase of deformation. Most of the rocks are strongly jointed and weather to form a blocky talus.

In the eastern half of Yukon-Tanana region, and extending into the Yukon Territory, contact metamorphism of the schists near granitic rocks has led to development of garnetiferous schists and staurolitic schists.

The Pelly gneisses are a series of orthogneisses and metaigneous rocks associated with the Birch Creek schist, the most abundant of these being intrusives. The gneisses are predominately granitic, but locally include darker varieties of monzonitic, dioritic and even gabbroic character. They grade from a rather massive gneiss to a feldspathic quartz-mica schist. The gneisses are usually characterized by many augen, usually of feldspar; biotite being the most abundant mica.

The rocks of the Birch Creek schist group are polymetamorphic and are thought to have undergone two periods of metamorphism. An early metamorphic event which produced the amphibolite facies was apparently followed by later low-grade recrystallization (Mertie, 1937).

The structure of the Birch Creek schist is very complex. Two periods of deformation have involved isoclinal and recumbent folding in addition to numerous faults. There are low structural trends, one to the northwest and one to the northeast. The northeast trend appears to be related to later metamorphic event. In the Yukon-Tanana area the regional trend of the cleavage is north 15° east and dipping 15° to 20° east. On the other hand, the regional trend of the cleavages in the Yukon Territory is north 40° west and dipping 31° northeast.

As previously mentioned, Canadian geologists have applied the name Yukon Group to the Birch Creek schists. Older geologic literature has often separated the Yukon Group into 3 subdivisions (1) Klondike schist - for igneous rocks (2) Nasina series - for metamorphic sedimentary rocks (3) Pelly gneiss - gneissic rocks. The Yukon Group was first defined by Cairnes (1912) for rocks along the Alaska-Yukon boundary. Cairnes original interpretation of the Birch Creek schist was found to be incorrect because he believed the Yukon Group to be older than the Tindir group, since the Yukon Group was more highly metamorphosed in comparison with the Tindir Group. What Cairnes failed to recognize was that the Tintina Fault separated the Yukon Group from the Tindir group.

The rocks of the Keno Hill region north of the Tintina fault were originally assigned to the Yukon Group. They are now believed to be late Paleozoic or early Mesozoic in age. It is now thought that the Yukon Group outcrops between the Shawkaw and Tintina faults on the Yukon Plateau and possibly extends into northern British Columbia forming part of the Cassiar Mountains.

Gunning (1957) states that a thick sequence of metamorphic rocks occur in this area. Parts of this thick formation have been placed in the Tenakihi group and the Wolverine complex. Gunning mentions that there is a strong resemblance between the Shuswap and these rocks in the Cassiar Mountains. Stockwell (1963) also suggests that the rocks of the Yukon Group in the Yukon resemble those of the Shuswap Terrain.

Distinct lithologies are now being mapped within the Yukon Group (Green and Roddick, 1962); certain units have been mapped separately, but as yet they have not been named. Green and Roddick have subdivided the Yukon Group as follows: (1) Dark green serpentinized ultrabasic rocks (2) Pale green quartz-muscovite chlorite schists, chloritic quartzite, other intermediate rock types (3) Grey-green micaceous quartzite, silvery quartz-mica schists (4) Greenstone and banded amphibolite gneiss (5) Granitic textured quartz-biotite gneiss, minor quartzite and schist. Thus, there seems to be a valid correlation between the Yukon Group and the Birch Creek schist. The outcrop is continuous and lithologies are very similar.

AGE OF THE BIRCH CREEK SCHISTS AND THE YUKON GROUP

Like Cairnes, Mertie considered the Birch Creek schists as early Precambrian and older than the Tindir group, which contrasts markedly both in lithology and the degree of metamorphism. Recent age determinations by radiometric methods have given no proof of a Precambrian age (Wasserberg et al, 1963). Therefore, it is possible that the Birch Creek schist is in part of wholly of Paleozoic age.

Age determinations have been performed on micas using $\text{Sr}^{87}-\text{Rb}^{87}$ and $\text{Ar}^{40}-\text{K}^{40}$ methods on samples from granites and from the polymetamorphosed Birch Creek schist. Samples of the schist near Jack Wade, Alaska (approximately 10 miles northwest of the Sixtymile Lead-silver ore occurrences) have yielded ages ranging from 177 million years to 187 million years. Biotite from the nearby Mt. Taylor batholith and from the Mt. Fairplay granite gave ages of 190 and 66 million years respectively. Samples of granites from the Circle Hot Springs and from

and Birch Lake have yielded ages of 71 and 134 million years respectively.

This data indicates that the Birch Creek schist has been locally metamorphosed at 120 to 180 million years penecontemporaneous with significant plutonic activity. If it is assumed that the Birch Creek schist is correlatable over the Yukon-Tanana region, the results suggest that the metamorphism has been less severe in the area near the northern portions of the Birch Creek schists. Wasserberg states that up to the present time no proof is available by isotopic methods that the Birch Creek schist is of Precambrian age.

Within the Yukon, the Geological Survey of Canada age determination No. 62-82 is of particular interest, since the sample was taken approximately 2.5 miles north of the lead-silver ore occurrence held by Connaught Mines. A K-Ar date on a biotite yielded an age of 200 million years. The biotite was taken from a granodioritic orthogneiss. In the past, earlier workers have considered that these granitic gneisses were of lower grade than the metamorphic rocks, both of which are widespread in the Yukon and Alaska (Leach and others, 1963) and were interpreted as products of Precambrian intrusion and metamorphism.

Green and Roddick (1962) suggest that a Precambrian age cannot be proven and that some of the metamorphosed sedimentary rocks are of Palaeozoic age. They make reference to some crinoid ossicles that were found a short distance south of the point where the Yukon River enters Alaska and several examples of similar rocks in Alaska. The collections indicate a Palaeozoic age for part of unit C on G.S.C. map 13-1962 among the unmetamorphosed rocks northeast of the Tintina fault.

The G.S.C. age determination 62-82 together with other gas deter-

minations (Fig. 6) do not uphold the concept of Precambrian intrusion and metamorphism; however, they tend to imply that the metamorphic rocks may have formed, or undergone a period of alteration, during the Early Mesozoic, prior to the emplacement of the Coast Range and Cassiar batholiths. In general, the ages for metamorphic rocks or the Yukon Group to the southeast of the Sixtymile area vary in age between 138 and 222 million years (Lowdon, 1960, 1961). These ages contrast the younger ages of 100 million years or less from fresher granitic rocks which appear to have intruded the Yukon Group and from the Coast Range and Cassiar batholiths. Granitic rocks related to an Early Mesozoic alteration may have supplied the granitic detritus which is found within the Early Jurassic conglomerates of the Whitehorse area, (Wheeler, 1961) as a granitic rock dated at 223 million years was collected from this vicinity (G.S.C. 59-10).

MESOZOIC ROCKS

The Cordilleran geosyncline existed throughout the Paleozoic era, continued on into the Mesozoic era, and at least through Late Triassic times. Fine-grained clastics, chert and limestone (which are the dominant rock types of the Triassic) are also common among the Paleozoic sediments laid down in the Cordilleran geosyncline, but are uncommon among the sediments of late depositional basins (Mineral and Water Resources of Alaska).

The end of the Triassic marks the approximate end of the Cordilleran geosyncline in Alaska and the Yukon. The warping of the land surface in the Middle Mesozoic times commenced earlier in southern and northern Alaska than in central Alaska and the central Yukon. Thus, the sediments found in the geosynclines of the interior Alaska and the Yukon are

Cretaceous in age. The filling of these geosynclines was essentially completed by the end of the Mesozoic and deformation followed. This deformation was but one of a major sequence of events that began in the Middle Triassic to Early Cretaceous time.

Following this deformation, the next orogenic event to affect Alaska and the Yukon took place during Early Cretaceous and it is believed that the uplifted rocks were completely eroded, as no traces of them have ever been found (Mineral and Water Resources of Alaska).

Many of the large granitic bodies in Alaska and the Yukon were intruded during the Mesozoic era, but many of these have not been accurately dated. However, some of the intrusives of Middle Jurassic age which have invaded Lower Jurassic strata in the south central portions of Alaska and the Yukon have furnished detritus to form the Upper Jurassic conglomerate (Wheeler, 1961).

Widespread mountain building took place at the end of the Cretaceous period, and the beginning of the Tertiary period. Thus, sediments which filled the Late Mesozoic geosyncline were uplifted along with other areas which follow the trends of geosynclines. At this time the predecessors of the present mountain ranges were formed. In northern Alaska and the Yukon, the rocks of the Brooks Range and the Rocky Mountains were deformed into east-trending folds some of which were overturned and thrust north.

Ages by radiometric methods on the Yukon-Tanana and Yukon Plateau regions (Wasserberg, 1963) and (Leech and others, 1963) indicate that large intrusions were emplaced during Late Triassic and Late Cretaceous times.

CENOCZOIC ROCKS

Alaska and the Yukon were emergent by the end of the Cretaceous period and mountain building has continued to the present. The Cenozoic was mostly a period of erosion. At times during the Tertiary period, local deformation of the land surface has produced several elongate basins of deposition (Gabrielse and Wheeler, 1960, Fig. 4) and (Mineral and Water Resources of Alaska, Fig. 9). Deposits of all epochs of the Tertiary are represented in these basins but the age of the deposits may differ from basin, and between different parts of the same basin.

Towards the end of the Tertiary, orogenic activity (which continued in the Quaternary) folded the Tertiary strata resulting in strong uplift to produce the present mountain ranges and plateaus.

During the Late Mesozoic and Cenozoic eras, igneous activity, both intrusive and extrusive, was important. The sedimentary rocks of Early or Late Cretaceous age were invaded by granitic rocks. Thus, for many of the intrusives this is the only evidence of their age.

With the exception of northern Alaska and the Yukon, Cenozoic volcanic rocks are widespread in western Alaska and the Yukon.

GEOLOGY OF THE LEAD-SILVER ORE OCCURRENCES

Within the area held by Connaught Mines Ltd., the rock surface is covered with a thick veneer of residual soil and rock fragments. This overburden ranges from 2 to 12 feet in thickness. Consequently, it is difficult to find many exposures of the underlying bedrock. The only good exposures of bedrock are located in the vicinity of the ore veins where the overburden has been stripped.

In the vicinity of the No. 1 and No. 2 veins, porphyroblastic

quartz plagioclase biotite muscovite gneisses outcrop (Plate 1, Fig. 1). These gneisses would appear to be equivalent to the Pelly gneisses which vary in age from 202 to 161 million years (Wanless et al, 1965).

Between the No. 2 and No. 3 veins, a quartz plagioclase biotite muscovite gneiss is found (Plate 1, Fig. 2). This gneiss is probably equivalent to the so-called Klondike schist (Wanless et al, 1965) varying in age from 138 to 175 million years.

Immediately to the north of the No. 3 vein, a small body of porphyritic granite outcrops (Plate 1, Figures 3 and 4). This body appears to be approximately 50 feet in diameter and up to the present time is the only known intrusive on the property.

The regional trend of the foliation in the metamorphic sequence is constantly $N40^{\circ} W$ with the foliation planes dipping at $31^{\circ} NE$. Strong lineations on the foliation planes plunge in a northwesterly direction.

GEOCHEMICAL SURVEY

INTRODUCTION

Geochemical prospecting for minerals includes any method of mineral exploration based upon systematic measurement of the chemical properties of a naturally occurring material. Most often measured is the trace content of an element or elements which may occur within residual soil, gossan, glacial till, vegetation, stream sediments and even water. Mapping of the variations in element content may lead to the detection of anomalous geochemical values and ultimately result in the discovery of ore (Hawkes, 1957). The intent in this study was to carry out a geochemical orientation survey which would enable the most efficient geochemical prospecting methods to be established.

CHOICE OF LOCATION FOR THE GEOCHEMICAL SURVEY

The three occurrences of lead-silver ore occur in veins which generally strike towards N 50°E ; these occurrences are indicated in Fig. 31. Figures 8 and 9 illustrate the type of terrain around each occurrence. Figure 9 shows the location of the No. 3 vein in the foreground and the No. 1 vein in the background. The location of the No. 2 vein is indicated by an arrow.

As seen from an examination of Figures 8 and 9, the No. 1 vein did not appear suitable for an extensive geochemical orientation survey, nor could the No. 2 vein be properly investigated owing to the fact that the residual soil overlying these veins had been greatly disturbed prior to the writer's arrival. Although some of the residual soil had been disturbed around the No. 3 vein, this area appeared to be the most favourable for a geochemical orientation survey.



Figure 8. No. 3 vein in the foreground (centre of slope) and the No. 1 vein in the background. The arrows indicate the location of the No. 1 and No. 2 veins.



Figure 9. No. 2 vein location indicating the haphazard and extensive removal of residual soil, thus making the area unsuitable for geochemical prospecting.

The selection of the area surrounding the No. 3 vein was based upon several factors. Firstly, the slopes were favorable for such a survey; the slope topography varying from 5° to 16° . Secondly, the dispersion patterns for silver, copper, lead and zinc could be effectively evaluated if the geochemical survey was carried out in the vicinity of a known occurrence. Such a procedure would facilitate the choice of that element most suitable for geochemical prospecting. Finally, from the interpretation of these results, an efficient pattern could be established for future reconnaissance geochemical prospecting of similar terrain.

SAMPLING

Once the area for the geochemical survey had been selected, a base line was established striking N 46° E. This line is referred to as 0-00 north and is indicated on Figures 20, 21, 22, and 23. The geochemical traverses were run at 100 foot intervals perpendicular to this base line, and the sample interval was every 50 feet along the traverses.

All samples were taken from the "B" soil horizon, that is 1 to 1.5 feet below the surface. Due to varying permafrost conditions (that is, permafrost was encountered from 1 to 3 feet below the ground surface) and the fact that numerous boulders are present in the residual soil, rapid manual sampling was considerably hindered. Consequently, a "Caterpillar" D-8 tractor equipped with a rear mounted three-tooth ripper was employed (Fig. 10). The ripper was dropped into the soil at 50 foot intervals along the traverses, and representative samples from the "B" soil horizon were easily obtained. The method of preparation



Figure 10. D-8 "Caterpillar" exposing the No. 2 vein by use of a three-tooth ripper. Note black goethite-rich gossan over vein.

of the samples for analysis is discussed in Appendix A.

The sample depth of 1 to 1.5 feet was determined by a preliminary survey using a "heavy metals" geochemical kit and a dithizone-toluene extraction. The concentration of heavy metals in the various soil horizons was determined by the intensity of the color in the immiscible layer. Figure 14 shows a typical soil profile in the area covered by the geochemical survey over the No. 3 vein.

ANALYTICAL PROCEDURES

A Perkin Elmer Model-290 atomic absorption unit was utilized to determine the concentrations of silver, copper, lead and zinc in the soil samples. Data relating to the atomic absorption unit is given in Appendix B.

Two methods of sample preparation were used. The first method involved an ammonium citrate-HCl leach, and the second method employed a hot nitric acid leach (Boyle, 1965). These methods are discussed in detail in Appendix A.

The principle reason for selecting the ammonium citrate-HCl leach was that anglesite ($PbSO_4$) is often found at or near the surface due to frost boiling. It was believed that the hot nitric acid leach would not be very effective in breaking down the $PbSO_4$ molecule. On this basis it was felt that the ammonium citrate-HCl leach would give a better recovery of lead. In order to test this primary supposition, 10 samples were analyzed using the two distinct chemical procedures. In addition, the residue from these samples was decomposed with HF and HCl and the concentrations of copper, lead and zinc were determined in the residues. A comparison of these two methods of sample preparation is given in Table 1.

The results in Table 1 indicate that the ammonium citrate-HCl leach gave a more complete extraction for all three elements than the nitric acid leach. Lead recovery was approximately 20% greater, copper recovery approximately 40% greater and zinc recovery approximately 30% greater. It was on the basis of these results that the ammonium citrate-HCl leach was chosen for the analyses of the soil samples.

TABLE I. COMPARISON OF ANALYSES ON 10 SOIL SAMPLES USING THE AMMONIUM CITRATE - HCl LEACH AND THE HOT NITRIC ACID LEACH.

AMMONIUM CITRATE - HCl LEACH				HOT NITRIC ACID LEACH			
PERCENT RECOVERY				PERCENT RECOVERY			
SAMPLE No.	Pb	Cu	Zn	Pb	Cu	Zn	Pb
3	94	92	79	72	53	46	
8	88	82	77	69	51	44	
15	91	92	77	71	49	43	
16	92	95	77	71	52	45	
18	94	88	78	69	48	43	
30	89	96	79	72	52	46	
31	90	91	78	69	50	44	
43	92	86	77	71	50	45	
45	92	91	76	72	48	45	
46	91	88	77	73	49	43	

RESULTS AND INTERPRETATION

Analyses for silver, copper, lead and zinc were performed on 860 soil samples. The results of these analyses are shown on the following figures: Figures 14, 15, 16 and 17, list the results of the analyses from the soil profile; Figures 18 and 19 list the results of the soil analyses across the No. 3 vein employing a 5 foot and 50 foot sample spacing; Figures 20, 21, 22 and 23 give the results of the soil sample analyses for the area covered by the geochemical survey in the vicinity of the No. 3 vein; and Figures 24, 25 and 26 list the soil samples analyses of 3 traverses run perpendicular to the No. 1 vein.

In this orientation study the samples were mainly taken from the mineralized zone. This posed a problem in determining the background value for the elements analyzed (Cu, Pb and Zn). Thus, a frequency distribution diagram was plotted for each element analyzed, and from this diagram the background levels were estimated as indicated in Figures 11, 12 and 13. The frequency distribution plots give large peaks at values which would be expected for background. However, these large peaks are biased toward higher element content values, as might be expected in an area involving anomalous samples. Therefore, the large "background" peaks are assumed to be of normal distribution on the lower side of the peaks and this distribution is assumed to be symmetrical on the other side of the peak for the background values (see Fig. 12). That is, a reasonably normal distribution of background values is assumed and used to establish a frequency range for which a mean background value can be computed. In general, the approximate mean value of the large peak, and its lower limit were estimated

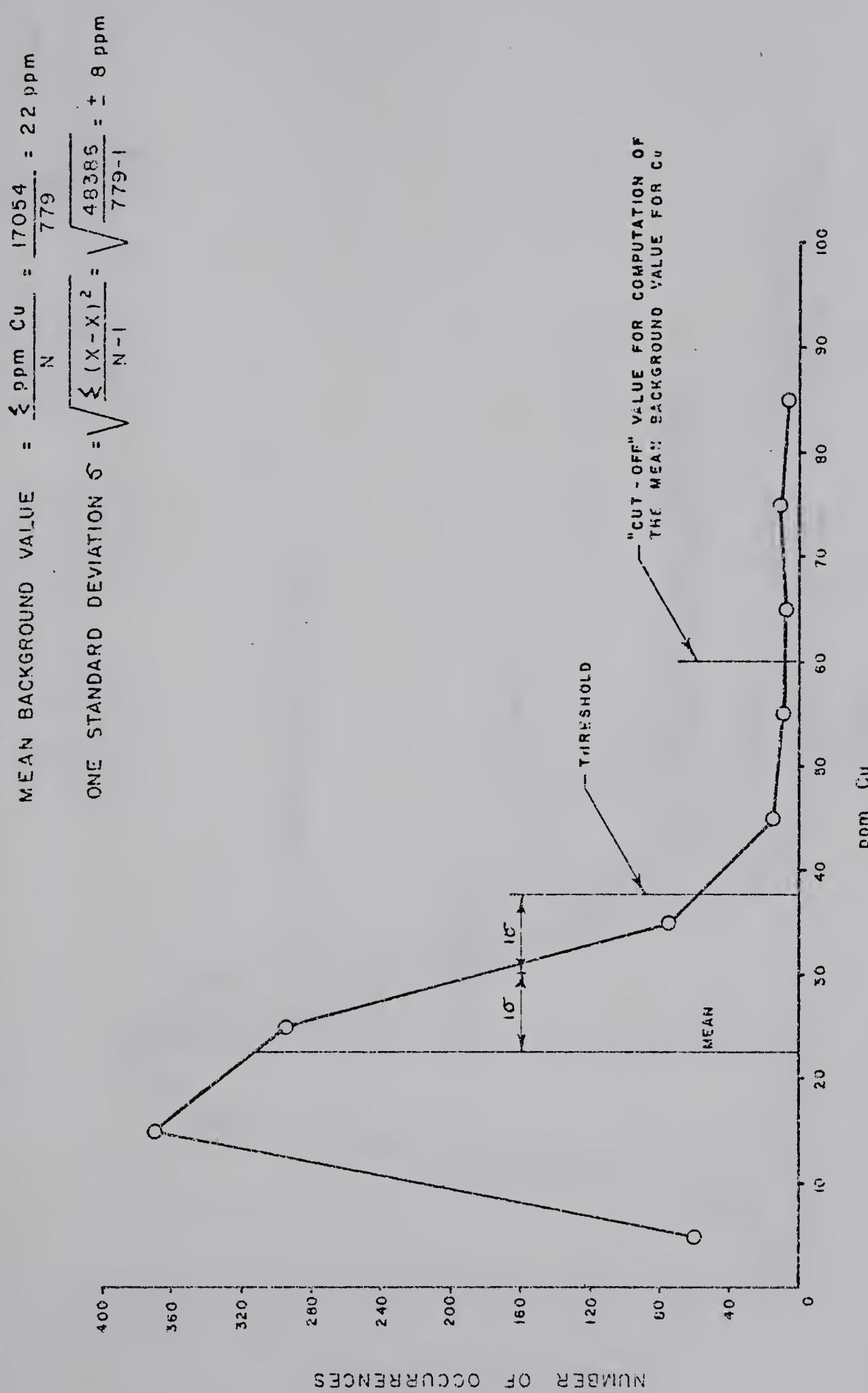


FIGURE II. FREQUENCY DISTRIBUTION FOR COPPER IN 779 SOIL SAMPLES

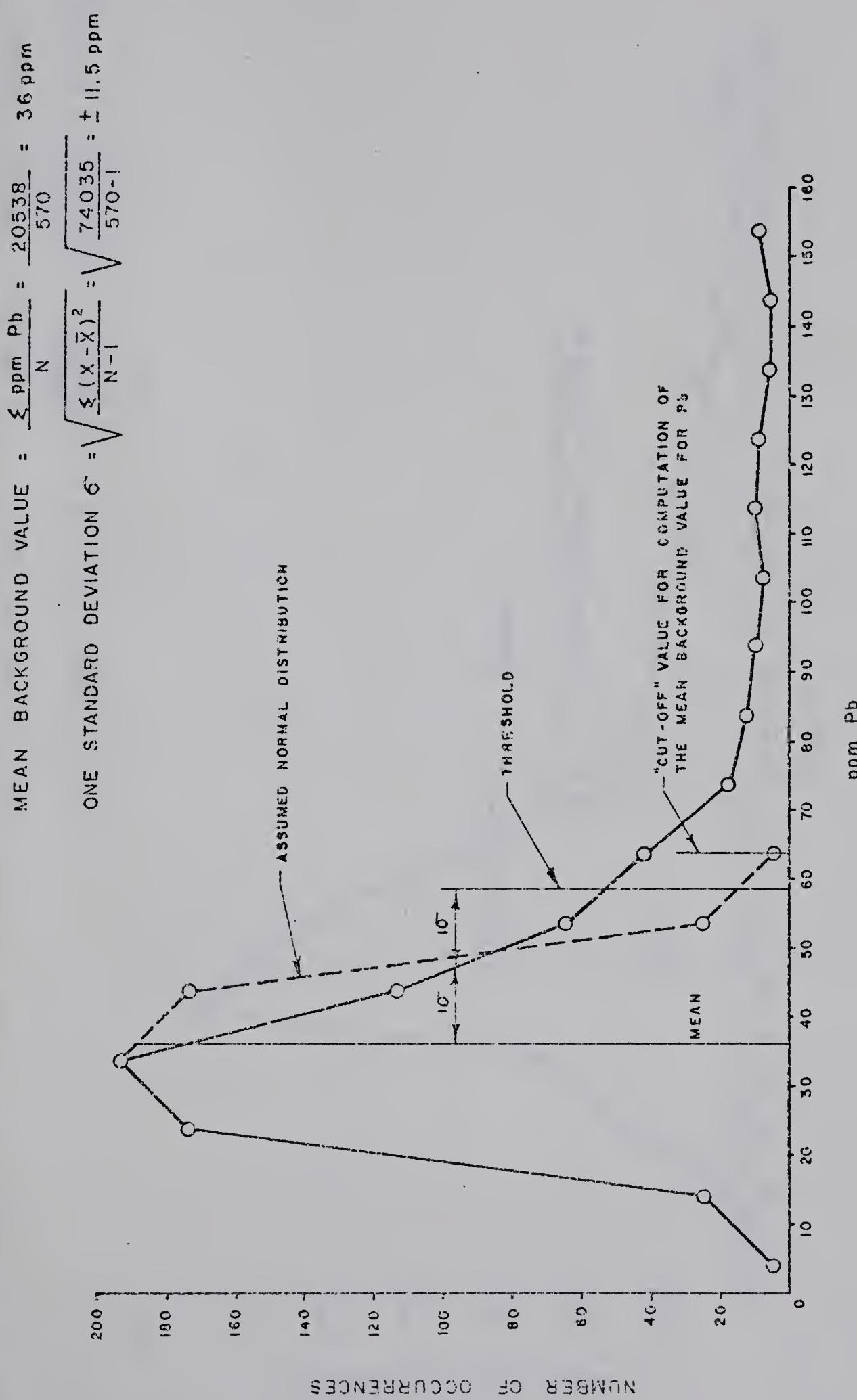


FIGURE 12. FREQUENCY DISTRIBUTION FOR LEAD IN 570 SOIL SAMPLES

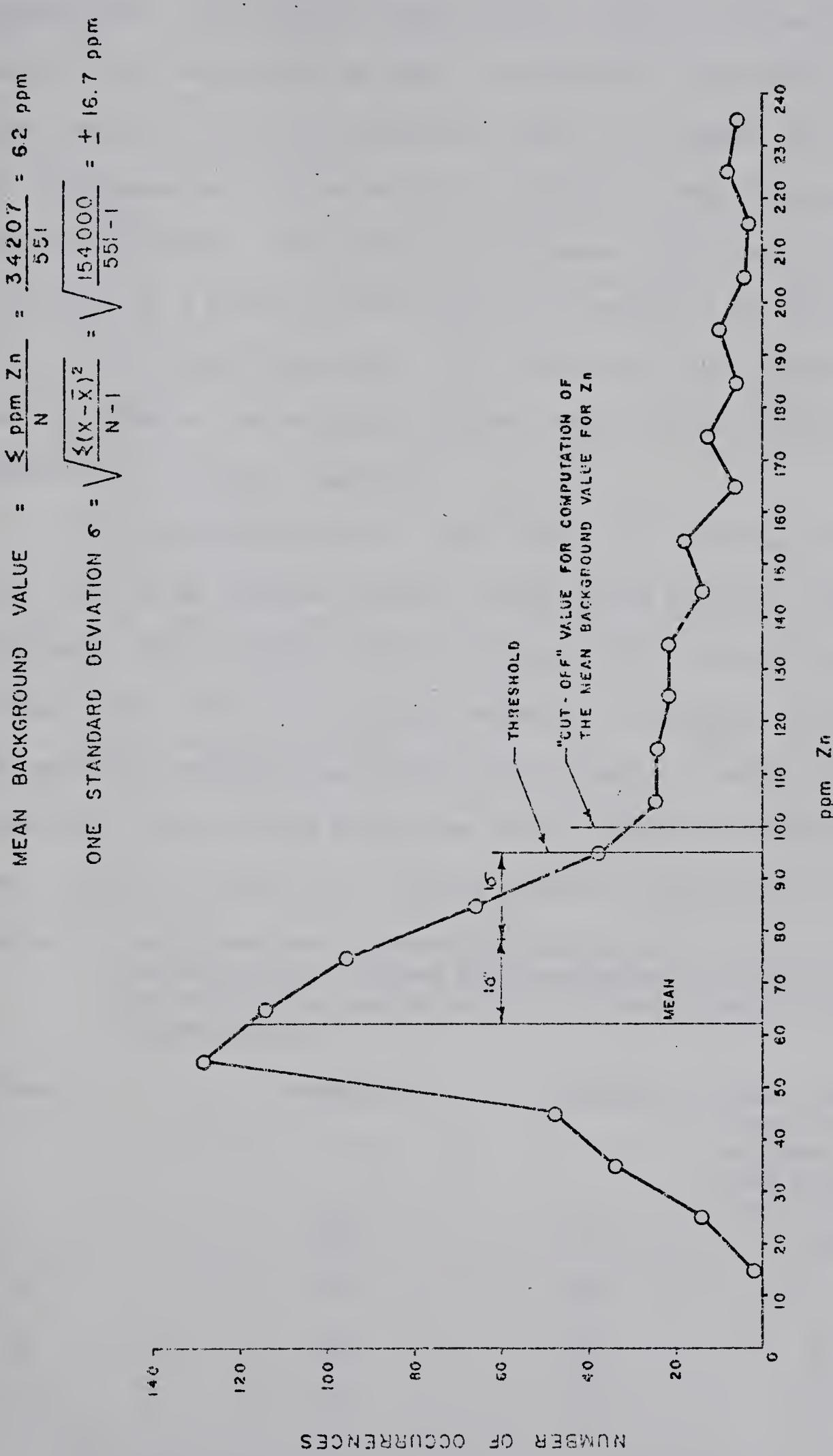


FIGURE 13. FREQUENCY DISTRIBUTION FOR ZINC IN 551 SOIL SAMPLES

graphically. The interval lying between these two values was then added to the mean value in order to arrive at a "cut-off" point for the distribution of the background values. Of course, some anomalous or "sub-anomalous" values would be included in this "background population" of values. This procedure increases the finally-determined threshold in a direction which tends to compensate for underestimating the background population. The values up to the "cut-off" point were treated as the background values, and the mean value and standard deviation of the mean computed.

The threshold value (the upper limit of the background values) was taken to be the mean element content value plus two standard deviations. This procedure is in conformity with the usual practice. Values higher than the threshold values are considered anomalous. It should be mentioned again that the inclusion of some likely anomalous values in the population of the background values makes this threshold value a very liberal maximum background limit.

Table 2. Background and threshold values in ppm for Cu, Pb and Zn in the area covered by the geochemical survey in comparison to the concentration of these elements in normal mineral soil.

Element	Background	Threshold	Minor Element Concentration in Normal Min- eral Soil (Mitchell, 1955)
	ppm	ppm	ppm
Cu	22	38	20
Pb	36	59	30
Zn	62	95	60

The minor element concentration in a normal mineral soil was compared to the background values computed from the frequency dis-

tribution plots (Figures 11, 12 and 13). These values are given in Table 2, and indicate that the method employed in determining these background values yields concentrations which compare favourably with the average concentration of these elements in a mineral soil.

A frequency distribution plot and threshold computation was not made for silver. The sensitivity of the atomic absorption analysis was such that approximately 0.1 ppm silver could be detected in the sample solution. Since 2 gm. samples were leached and a final sample solution volume of 20 ml was used, the detection limit for silver in the soil samples is approximately 1 ppm. The background level of silver in normal soils is somewhat lower than 1 ppm, and thus the background values could not be determined. Barely detectable amounts of silver were plotted as "trace" (T) in Fig. 22A, while the values were plotted for measurable amounts of silver. All silver values 1 ppm or greater are almost certainly anomalous.

A number of soil samples were taken 12 to 20 miles away from the area in order to estimate the regional background values for Cu, Pb, and Zn in barren soil. These samples yielded average values of 26 ppm for Cu, 47 ppm for Pb, and 88 ppm for Zn. Comparing these results with those of Table 1, it is evident that these figures are higher than those for normal mineral soil. Subsequent examination of geological maps has revealed that, unfortunately, the samples were taken along the regional trends in line with the lead-silver ore occurrences south of the Sixtymile River. It is possible that these samples taken to establish background may also be in a belt of weak mineralization.

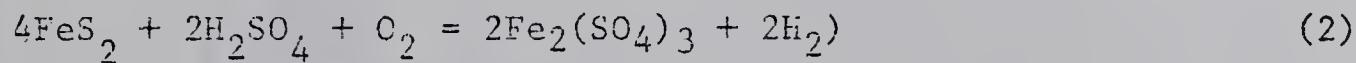
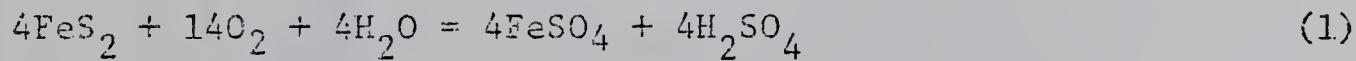
Before proceeding to a consideration of dispersion patterns for the elements in the areas covered by the geochemical survey, we should

first consider the oxidation processes which have taken place in the vicinity of these mineral veins. The interpretation of the oxidation processes is based on information obtained from publications by Boyle (1965) and Blanchard (1968).

Within the vicinity of these mineral veins oxidation processes would be due to the action of ground waters carrying dissolved oxygen (and carbon dioxide). Thus, the mobility of elements would depend on the solubility of their salts as sulfate ions or as carbonate ions and upon the local pH and Eh. The passage of these waters from environments with oxidizing conditions to those with reducing conditions would cause the precipitation of new minerals, and the remaining soluble components would be dispersed. The meteoric waters passing through these veins would undergo multiple changes due to their reaction with the gangue and ore minerals. The resulting chemical reactions would involve compounds of Ag, Cu, Pb, and Zn.

The spectrographic analyses (Table 3) indicate no detectable traces of Zn in any of the veins. However, iron is present within the massive galena. This iron would most likely be present in the form of finely disseminated pyrite. Therefore, the oxidation of galena by groundwater containing oxygen and carbon dioxide might involve the following reactions:

I. Initial oxidation of pyrite



Where the supply of water is not constant, the sulfide may not be oxidized equally. The formation of ferric sulfate from oxidizing pyrite may be expressed as follows:

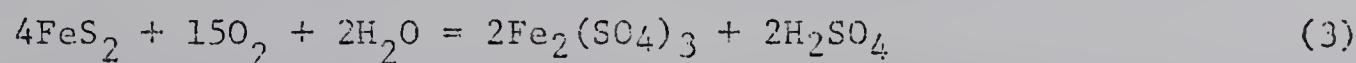
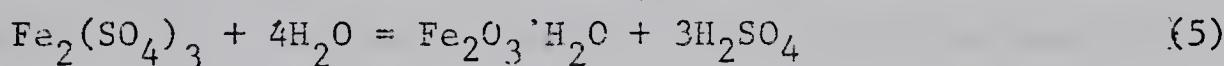
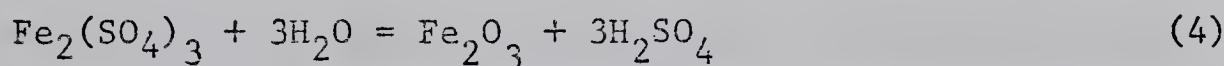


TABLE 3. SPECTROGRAPHIC ANALYSES OF GALENA SAMPLES FROM THE THREE OCCURRENCES.

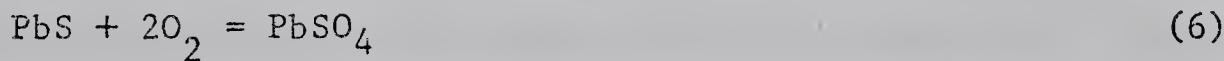
VEIN No.	MAJOR CONSTITUENTS	ESTIMATED CONCENTRATION			TRACES
		1%	0.01% TO 0.1%	0.001% TO 0.01%	
1	Pb	Sb, Al, Ag	Si, Mg, Bi, Fe, Cu	Sn, Ti, Ca	Mn, Mo, As
1	Pb	Sb, Al, Cu, Ag	Si, Mg, Si, Fe, Ca	Sn, As, Ti	
1	Pb	Sb, Al, Cu, Ag, As	Si, Mg, Bi, Fe, Ca	Sn, Ti	Mo
2	Pb	Sb, Bi, Al, Cu, Ag	Si, Mg, Fe, Ca	Sn, Ti, As	Mo
3	Pb	Si, Sb, Bi, Al, Cu, Ag	Mg, Fe, Ca	Sn, Ti	Mn, As, Ni, Mo
3	Pb	Sb, Bi, Al, Cu, Ag	Si, Mg, Fe, Ca	Sn, Ti	Mg
3	Pb	Si, Sb, Al, Cu, Ag	Mg, Fe, Ca	Sn, Ti, As	Mo

The foregoing equation is a combination of equations (1) and (2). As it is unlikely that oxidization of pyrite will yield ferrous or ferric ions exclusively, variable proportions of Fe^{++} , Fe^{+++} , SO_3^{--} , and SO_4^{--} ions would be present. The presence of this released iron is indicated by the abundance of limonite in the numerous veins and faults adjacent to the lead-silver ore occurrences and above the lead-silver orebodies themselves.

Since ferric iron is readily precipitated, its persistence is ubiquitous in the leached outcrops and on well jointed rock surfaces where it forms black coatings of goethite. The formation of goethite probably involves the following reactions:



2. The oxidation of galena may be represented by the following reactions:



Up to the present time no cerussite has been found in association with the galena or the anglesite. The apparent lack of cerrusite may be due to unfavourable conditions leading to the formation of this mineral. That is, if alkaline conditions and surface waters rich in carbonate are not present, cerussite will not form (Garrels and Christ, 1965).

The assays and the spectrographic analyses indicate that copper is present in very low quantities (approximately 0.32%) in the galena veins. In the oxidation of sulfides, the copper would be converted to a cupric sulfate (CuSO_4). This cupric sulfate could in turn

attack the galena to yield covellite as shown in the following equation:



This assemblage of minor amounts of covellite (CuS) surrounded by anglesite has been observed in the polished sections from the Sixty-mile area (Plate III, Fig. 5). Furthermore, much of the copper, once it has been converted to CuSO_4 , was probably transported in solution by groundwater as cupric sulfate.

At the present time, it is not known if any deposits of sphalerite exist in combination with the galena. Thus, the source of the large dispersion patterns of zinc have yet to be investigated. The spectrographic analyses do not give any indication of zinc in the ores.

Electron probe analyses of selected ore specimens have indicated that most of the silver is present in the form of an Ag-Cu-S sulfide. During the oxidation of galena, the silver was probably released as a sulfate in the same manner as galena converts to anglesite. There are a number of alternate routes for the dispersion of silver thus released. Silver may either be associated with anglesite under mildly acid conditions, or it may be absorbed in the limonitic vein material, or very small amounts of silver can be dispersed by ground water or by mechanical processes such as soil creep or solifluction.

The first series of dispersion patterns deal with the distribution of Ag, Cu, Pb, and Zn in the soil profile immediately above the No. 3 vein (Figures 14, 15, 16, and 17). Figures 14, 15, and 16 show the vertical variations in Ag, Cu, and Pb resulting from chemical and mechanical dispersion. Figure 17 provides no definite indications of a vertical dispersion pattern for zinc; (there are a number of high

values towards the right of the galena vein which could be considered as erratic). Figures 14 and 16 show some high values for Ag and Pb to the left of the galena vein. These anomalous values are attributed to the presence of a highly oxidized vein some 41 feet to the south of the No. 3 vein.

Figures 18 and 19 show the distribution of heavy metals in the residual soil along traverses across the No. 3 vein. The traverse in Fig. 18 has a 5 foot sample interval and the traverse in Fig. 19 has a 50 foot sample interval. These traverses show strong variations in the contents of lead, and silver, but not zinc and copper. Of particular interest are the sharp anomalies for lead in both traverses. In Fig. 18 the lead values are somewhat erratic. This may be attributed, in part, to frost boiling action causing local concentrations of lead ore. Pieces of galena and anglesite were noted in the soil samples when they were crushed and sieved prior to chemical analysis.

The lead anomalies in both Figures 18 and 19 are broad. In Fig. 19 the lead anomaly appears to extend for a minimum distance of 700 feet downslope from the vein. In Fig. 18 a small anomaly occurs immediately above the galena vein; however, the sharpest anomaly occurs some 10 feet to the north of the No. 3 vein.

The graphs for Ag and Cu in Figures 18 and 19 show some correlation with the anomalous lead peaks. Copper is somewhat erratic and has a fairly low concentration; (there are several weak anomalies which correlate with anomalous lead values). The silver anomalies are reasonably intense and the peaks show a definite correlation with the copper and lead peaks. The graphs show the relative immobility of silver in that measureable silver concentrations are obtained only in positions

TYPICAL SOIL PROFILE

Soil profile diagram showing horizons A0, A1, A2, B, and C. The profile is divided into several distinct layers. At the top is a thin, dark layer labeled A0. Below it is a layer labeled A1. A2 is a thick, light-colored layer. Below A2 is a layer labeled B. The bottom layer is labeled C. Arrows point from the labels to their respective layers in the profile.

AO UNDECOMPOSED, MATTED ORGANIC LAYER, ROOTS AND MOSS

AI ORGANIC LAYER, DECOMPOSED ROOTS, MOSS, HUMOUS

A2 LIGHT COLORED HORIZON, 1" TO 2" THICK, ZONE OF ELUVIATION

B YELLOWISH BROWN CLAY HORIZON CONTAINING SOME ROCK FRAGMENTS

C MOSTLY ANGULAR ROCK FRAGMENTS AND SOME CLAY

SCALE: 1/2" = 1 Foot (Vertical)

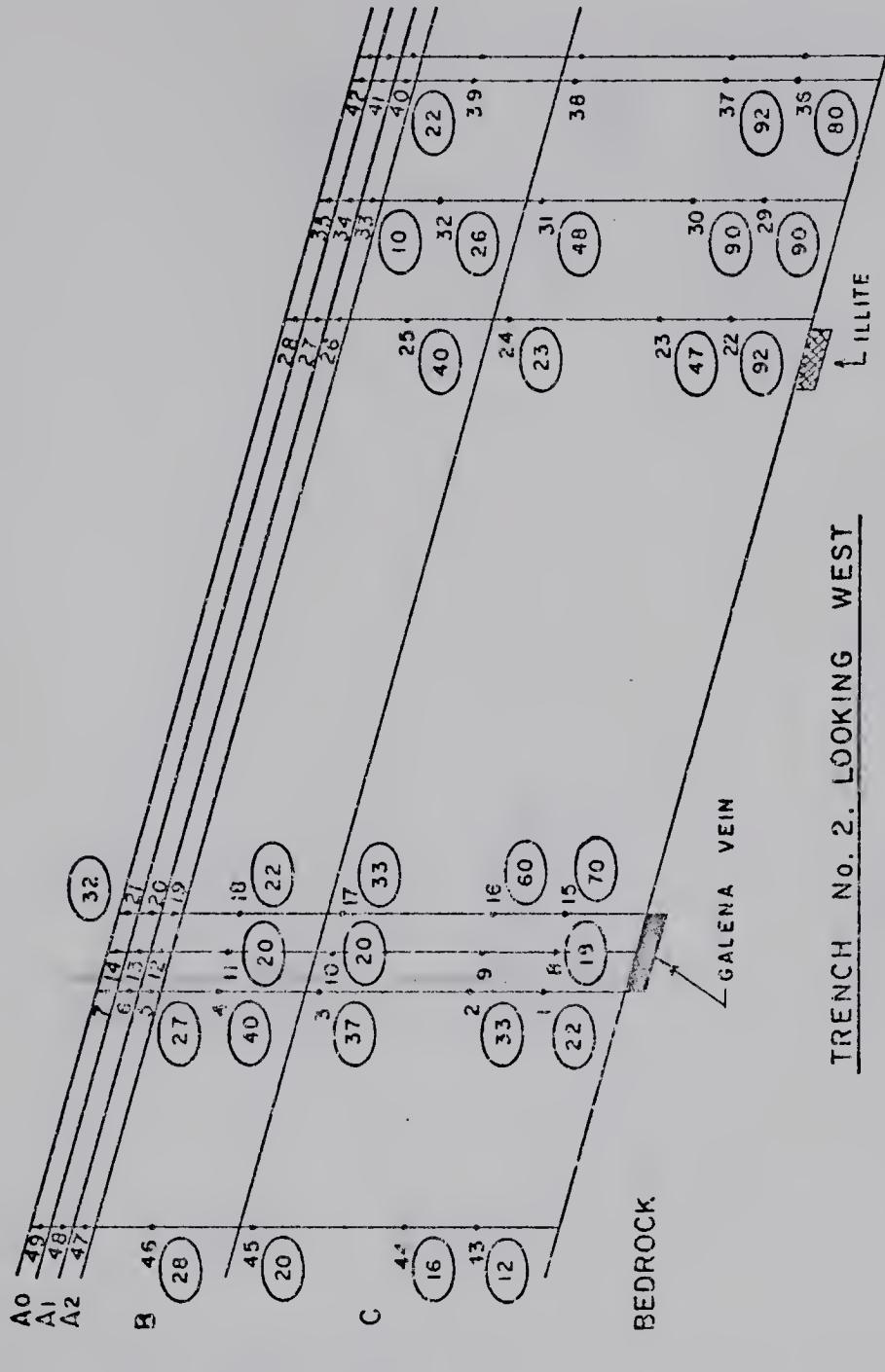
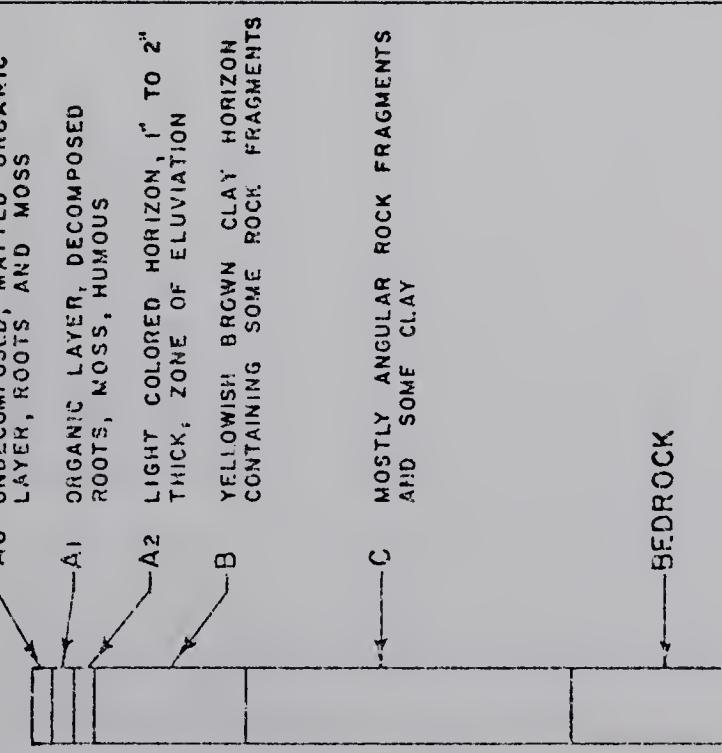
SCALE: VERTICAL 1/2" = 1 FOOT
HORIZONTAL 1/2" = 5 FOOT

LEGEND SAMPLE No. 3 -
ppm Ag

FIGURE 14. SILVER CONTENT IN THE SOIL PROFILE OVER THE NO. 3 VEIN

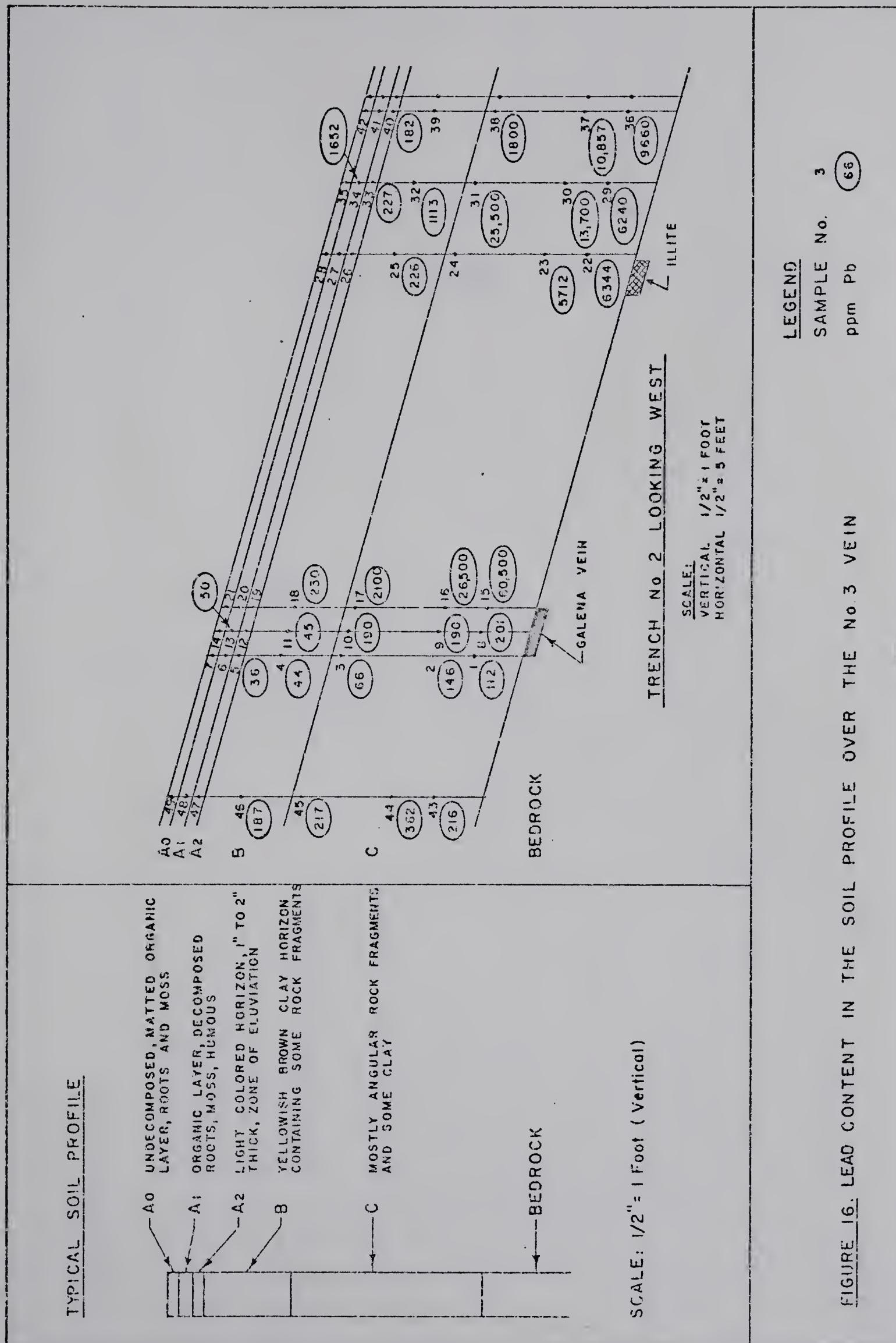
TYPICAL SOIL PROFILE

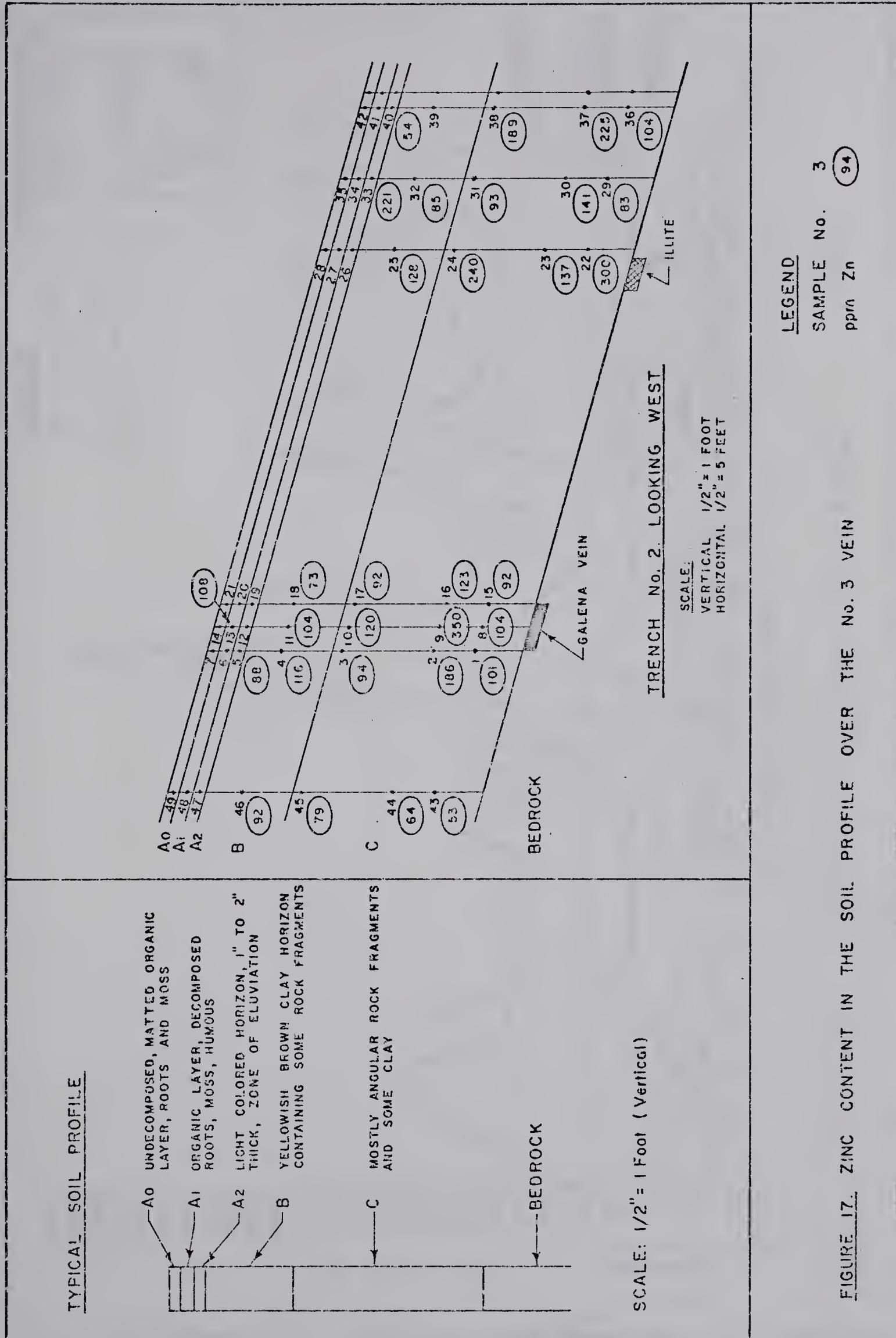
A₀ UNDECOMPOSED, MATTED ORGANIC
 LAYER, ROOTS AND MOSS
 A₁ ORGANIC LAYER, DECOMPOSED
 ROOTS, MOSS, HUMOUS
 A₂ LIGHT COLORED HORIZON, 1" TO 2"
 THICK, ZONE OF ELUVIATION
 B YELLOWISH BROWN CLAY HORIZON
 CONTAINING SOME ROCK FRAGMENTS
 C MOSTLY ANGULAR ROCK FRAGMENTS
 AND SOME CLAY



LEGEND
 SAMPLE No. 3
 ppm Cu 37

FIGURE 15. COPPER CONTENT IN THE SOIL PROFILE OVER THE NO. 3 VEIN





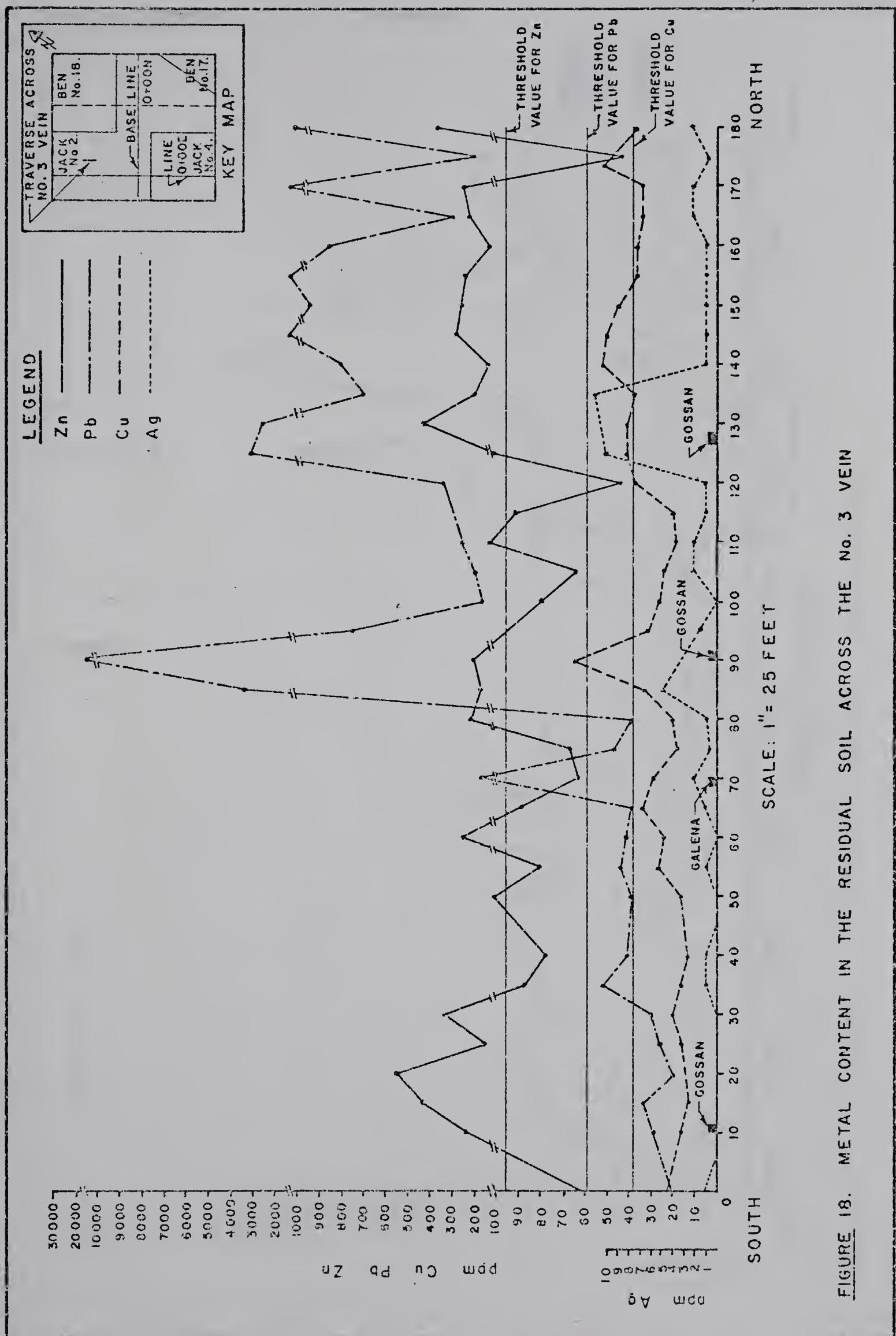
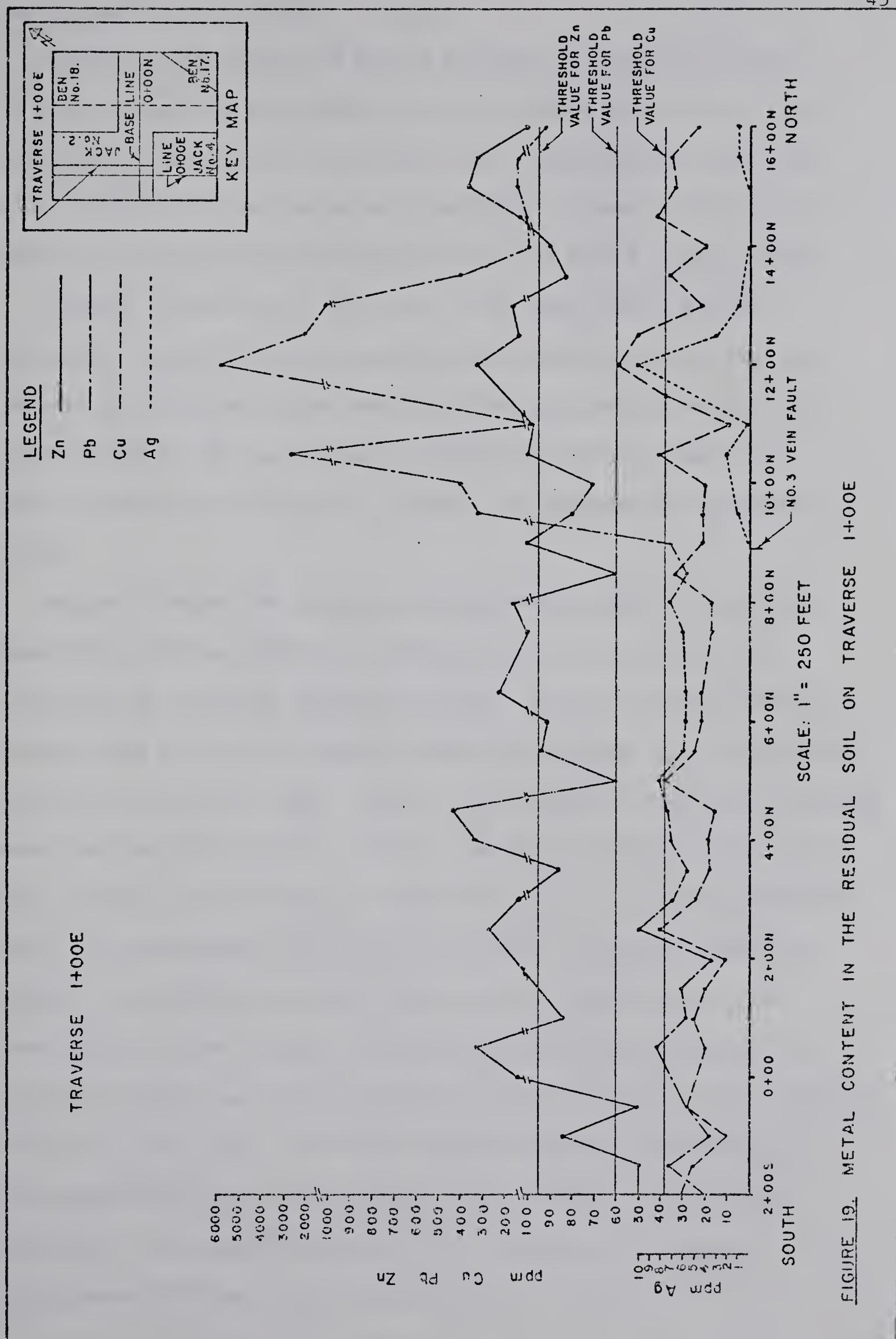


FIGURE 18. METAL CONTENT IN THE RESIDUAL SOIL ACROSS THE No. 3 VEIN



superadjacent to the veins.

Finally, both Figures 18 and 19 disclose the erratic behavior of zinc in that the distribution of this element shows little if any correlation with copper, silver and lead. These figures verify that zinc would be of little value as a pathfinder element in location of the type of mineralization found in the No. 3 vein in this terrain.

Figures 20 and 20A, 21 and 21A, 22 and 22A, and 23 and 23A illustrate the distribution patterns and concentrations of Pb, Ag, Cu, and Zn in the main area covered by the geochemical survey. The contours for Cu, Pb, and Zn begin with the threshold values for these elements (see Table 2). However, the contours for Ag begin at 1 ppm.

Figure 20 shows the distribution pattern for lead. In general, lead has a very low chemical dispersion, as a result of its low solubility as a sulfate or hydrous oxide. Figure 20 clearly demonstrates this fact as the anomalous lead values begin in the immediate vicinity of the No. 3 vein. However, the anomalous values are "smeared" downslope away from the No. 3 vein. The shape and the extent of the lead anomaly is due in part to the action of soil creep and solifluction. At approximately the 3500 foot contour, where the tree-line begins, the permafrost is much closer to the ground surface than above the 3500 foot contour. Thus, where permafrost is present in the upper substratum, the percolation of water from the thawed ground is hindered in the summer, and this creates conditions for saturated flow-earth during the summer season (Troll, 1958). As mentioned previously, the vegetation appears to be flowing in mats down a valley some 1000 feet to the north of the No. 3 vein.

NE

BEN No. 18.

JACK No. 2.

JACK No. 1.

• 10+00N

15+00N

• 0400S

15+00S

4400W

5400E

3600E

0400E

29+00E

35+00E

3700E

15+00E

10+00E

0400E

5+00E

3400E

3500E

3600E

4+00E

3400E

3500E

3+00E

3400E

3500E

3600E

2+00E

3400E

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1+00E

3400E

3500E

3600E

0+00E

3400E

3500E

15+00E

3400E

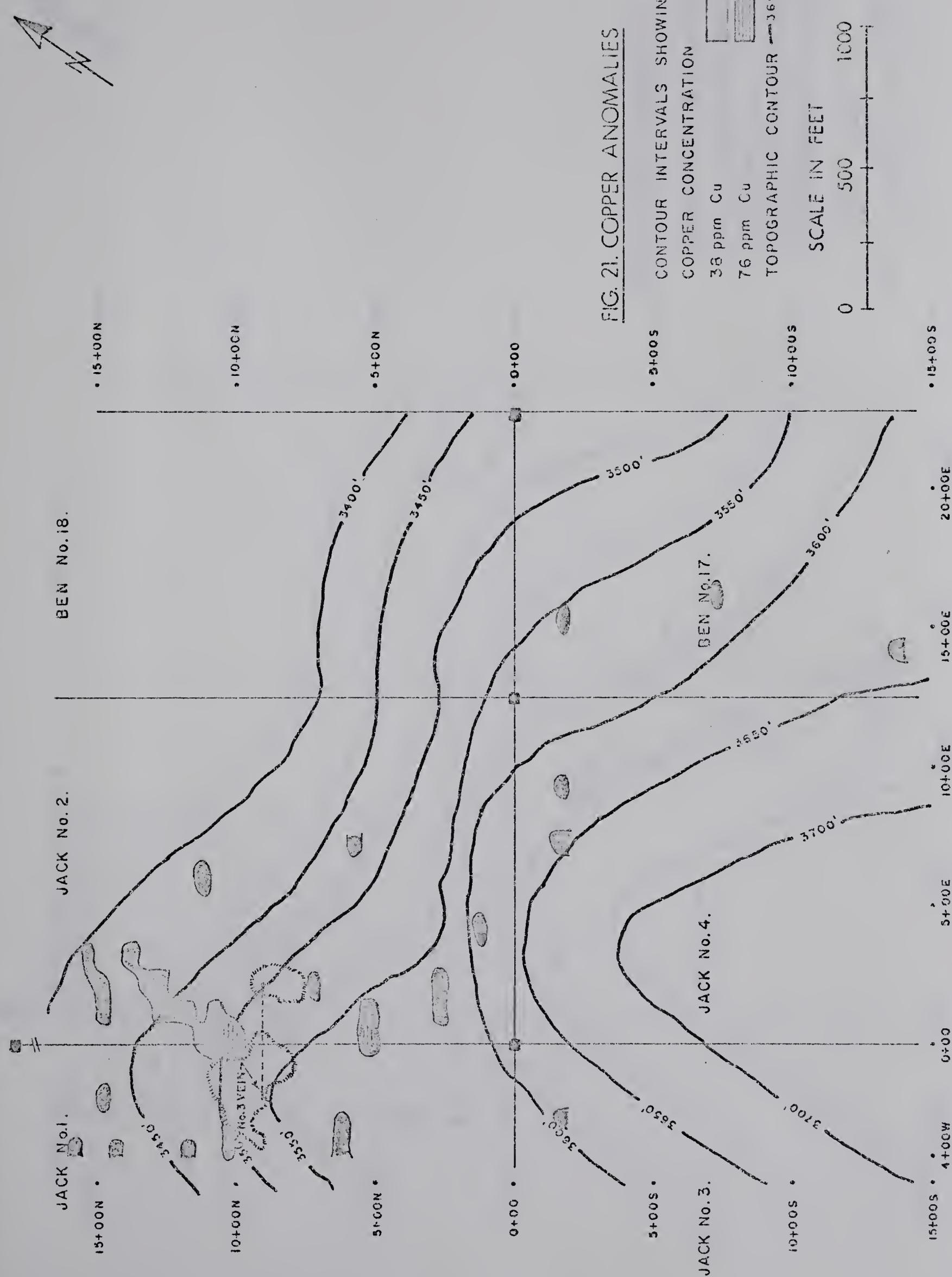
3500E

3600E

15+00E

3400E

<p



JACK No. 1.

15+00N

JACK No. 2.

BEN No. 18.

15+00N

10+00N

5+00N

0+00

5+00S

10+00S

15+00S

20+00S

25+00S

30+00S

35+00S

40+00S

45+00S

50+00S

55+00S

60+00S

65+00S

70+00S

75+00S

80+00S

85+00S

90+00S

95+00S

100+00S

105+00S

110+00S

115+00S

120+00S

125+00S

130+00S

135+00S

140+00S

145+00S

150+00S

155+00S

160+00S

165+00S

170+00S

175+00S

180+00S

185+00S

190+00S

195+00S

200+00S

205+00S

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785+00S

790+00S

795+00S

800+00S

805+00S

810+00S

815+00S

820+00S

825+00S

830+00S

835+00S

840+00S

845+00S

850+00S

855+00S

860+00S

865+00S

870+00S

875+00S

880+00S

885+00S

890+00S

895+00S

900+00S

905+00S

910+00S

915+00S

920+00S

925+00S

930+00S

935+00S

940+00S

945+00S

950+00S

955+00S

960+00S

965+00S

970+00S

975+00S

980+00S

985+00S

990+00S

995+00S

1000+00S

1005+00S

1010+00S

1015+00S

1020+00S

1025+00S

1030+00S

1035+00S

1040+00S

1045+00S

1050+00S

1055+00S

1060+00S

1065+00S

1070+00S

1075+00S

1080+00S

1085+00S

1090+00S

1095+00S

1100+00S

1105+00S

1110+00S

1115+00S

1120+00S

1125+00S

1130+00S

1135+00S

1140+00S

N
W



Figure 20 shows several other areas where anomalous lead values occur. The one region of particular interest lies near the southern boundary of the geochemical survey area between the Jack No. 4 and the Ben No. 17 claims. At present time, it is not known whether or not any silver-lead mineralization is present. Similarly, it is not known if any mineralization is associated with the other small anomalies in the east central portions of Fig. 20.

Figures 21 deals with dispersion patterns for copper. Only one major pattern is evident. It extends downslope in a northerly direction in the vicinity of the No. 3 vein. The highest concentration of copper appears at a point 10+00 N on the C+00 traverse where the No. 3 vein is highly oxidized. The high value of copper at this particular point would suggest that copper is slightly enriched in the oxidized zone of the No. 3 vein. This is supported by the fact that a noticeably higher concentration of covellite occurs in the oxidized ores of the No. 3 vein.

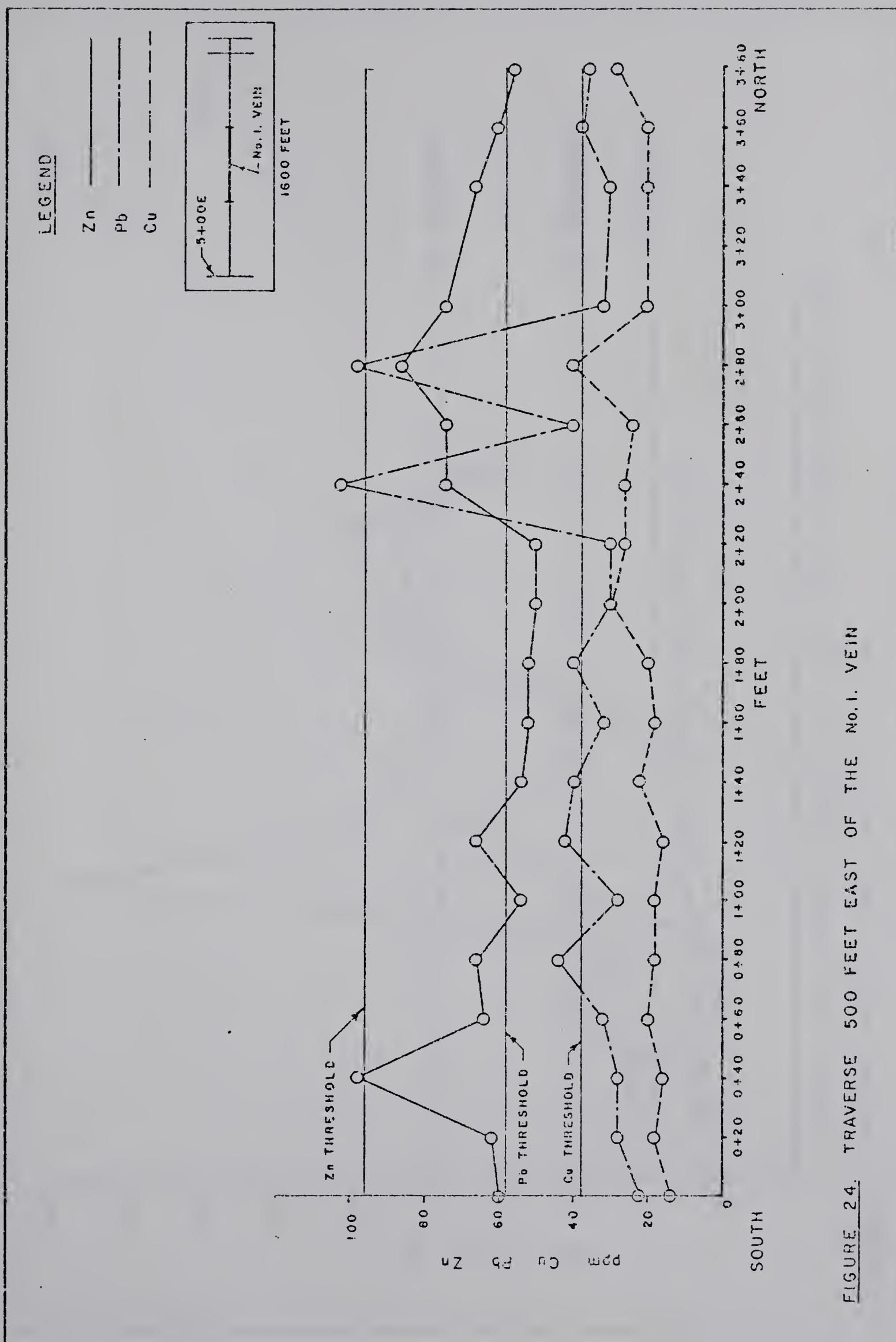
The limited dispersion pattern for copper could be due to the formation of secondary copper minerals. Other factors which might limit the mobility of copper would be pH, and to lesser extent its coprecipitation with limonite and sorption onto organic matter and clay minerals. Boyle and Cragg (1957) stated that in the Keno Hill area there is rarely any marked concentration in the copper content of the soils. The weak dispersion pattern in Fig. 21 appears to parallel the findings of Boyle and Cragg.

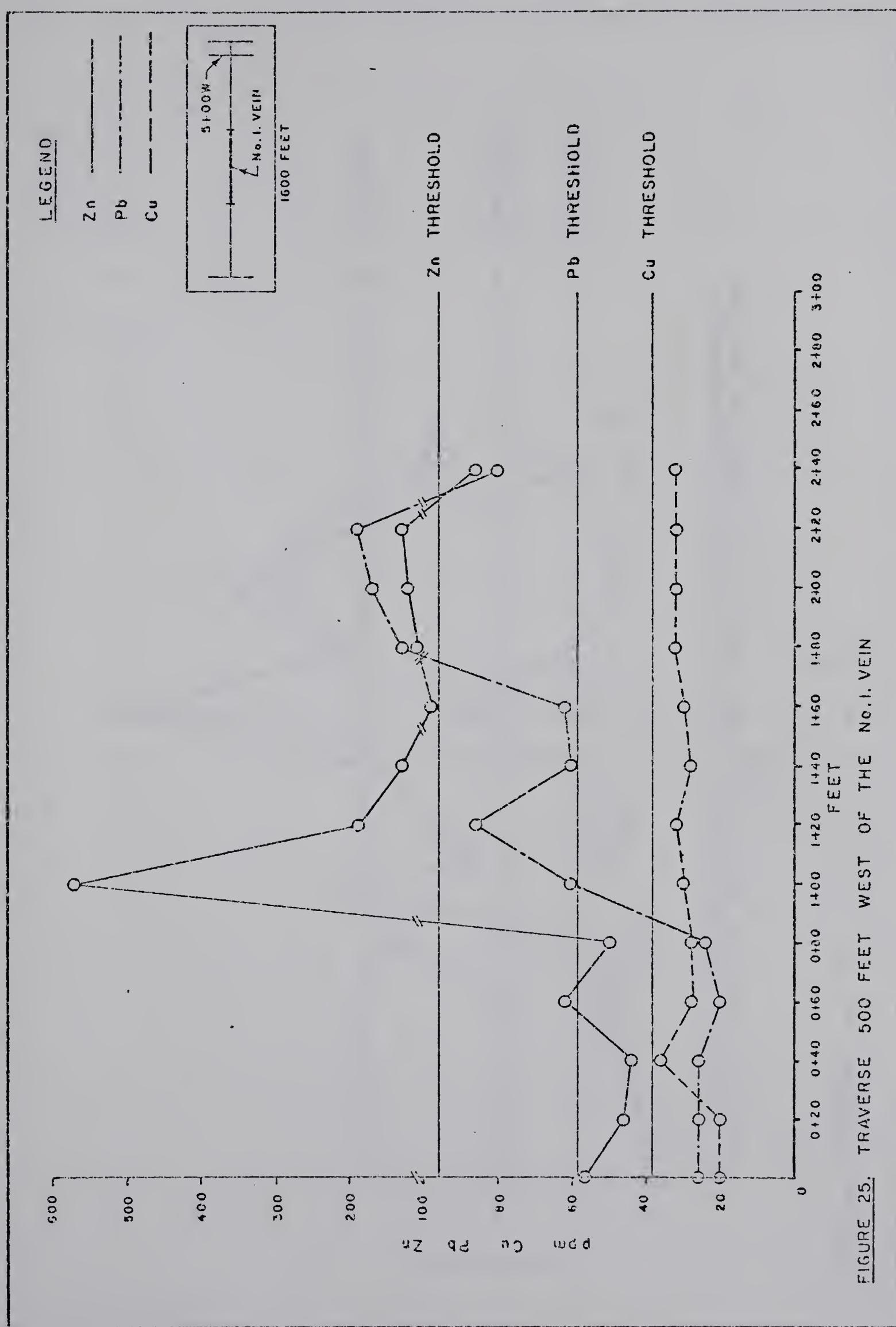
Figure 22 illustrates the dispersion of silver. The absolute concentration of silver is very low, but values of 1 ppm are considered to be anomalous. There are several small areas where the concentration exceeds 5 ppm. As in the case of lead, silver appears to be relatively immobile,

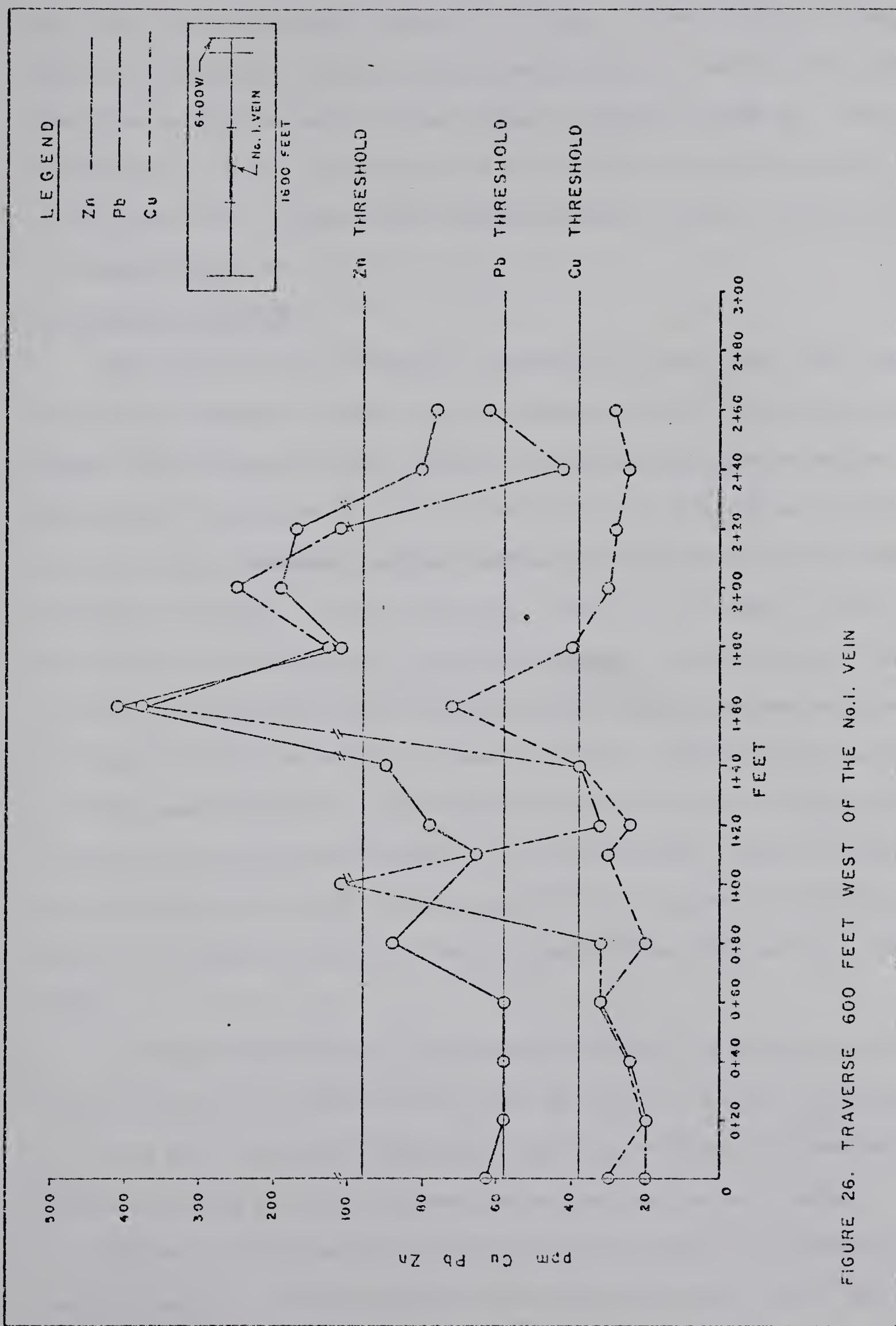
and follows a similar dispersion pattern near the No. 3 vein. The factors which would limit the dispersion of silver would be its association with anglesite or absorption by limonitic vein material. Small amounts of silver could be dispersed by groundwater. However, in this case the main dispersive agents appear to be solifluction and soil creep. Figure 22, like Figure 20, indicates a small anomaly near the southern boundary of the geochemical survey area between the Jack. No. 4 and the Ben No. 17 claims.

Finally, the dispersion patterns for zinc are shown in Figure 23. The dispersion pattern for zinc also shows a marked concentration to the north of the No. 3 vein. However, unlike lead and silver, there is an anomalous region of zinc values to the south of the No. 3 vein. Up to the present time no further work has been done in order to ascertain whether or not this anomaly is due to the presence of a zinc bearing lode. The fact that no widespread anomalies occur in the eastern portion of the area covered by the geochemical survey strongly suggests the possibility of zinc mineralization. Since zinc is a strongly dispersed element and shows little correlation with the anomalies in Figures 18 and 19, too much weight should not be placed upon zinc as a suitable indicator element for such lead-silver mineralization.

A limited amount of geochemical work was performed in the vicinity of the No. 1 vein. Three short traverses were run perpendicular to the known strike of the vein. These traverses were located 500 feet east (Fig. 24), 500 feet west (Fig. 25), and 600 feet west (Fig. 26) of the showing. The traverses were run over patterned ground (where active solifluction was present) in an attempt to detect any anomalous heavy metal values. All three figures show two distinct peaks for lead. In







all three cases the copper values are very low, but show some correlation with the lead peaks. The only significant change is that the zinc peaks show some correlation with the lead peaks in Figures 25 and 26. Subsequent trenching to a shallow depth revealed two parallel veins filled with gossan and illite. These veins correlate exactly with the two peaks shown on Figures 25 and 26.

EVALUATION OF RESULTS

The results of the geochemical orientation survey reveal that lead is the best indicator element for soil sampling in the Sixtymile district. Copper and silver show fairly definite correlation with the anomalous lead values, but in general the relatively lower concentration of these elements in the anomalous residual soil makes them less practicable as pathfinder elements. On the other hand, zinc does not appear to show any definite correlation with the lead-silver ore mineralization. Figures 18 and 19 clearly show that the anomalous lead values are located close to the source of the lead-silver ore mineralization. The fact that no cerussite has been observed in association with galena or anglesite indicates that lead is in the form of $PbSO_4$ in the residual soil. Thus, the sharp anomalies which have been observed reveal that low chemical dispersion of lead is the result of its low solubility as a sulfate (Garrels and Christ, 1965).

Although lead is highly immobile as a sulfate, the effects of mechanical dispersion are evident to the north of the No. 3 vein. This dispersion is due to soil creep and solifluction which has resulted in anomalous lead values extending at least 700 feet down slope from the No. 3 vein.

Figure 21 indicates that the dispersion of copper is difficult to assess because of its low content within the galena veins and in the

residual soil. Figures 18 and 19 show that there is little marked concentration of copper over the No. 3 vein. In addition, copper has a high mobility in the form of cupric sulfate and thus should be readily dispersed.

The silver concentration in the residual soil adjacent to mineralization tends to be high relative to its concentration in normal mineral soil. This concentration is due to several factors. Silver apparently tends to be absorbed by anglesitic or limonitic vein material. The wide dispersion pattern to the north of the No. 3 vein is due to the action of soil creep and solifluction. However, silver is generally an unsuitable indicator element for geochemical prospecting in this area because of the greater difficulty of determining very small amounts of silver.

Zinc is the most strongly dispersed element. This is supported by the fact that zinc is highly soluble as a sulfate, and that zinc appears to decrease in concentration in the oxidized parts of sulfide lodes (Boyle and Cragg, 1957). Zinc is readily taken up by vegetation and whenever peat or bog is present, it shows a very marked concentration. The erratic dispersion of zinc is shown in Figures 18 and 19. In these figures zinc shows little if any correlation with the source of the lead-silver ore mineralization. This erratic nature of zinc limits its application as an indicator element in isolating lead-silver ore mineralization of the type studied in this investigation.

In reference to Fig. 23 the area to the south of the No. 3 vein shows a fairly extensive region of high zinc values. The source of the zinc may be due to the presence of zinc within the country rock, or there may

be a zinc-bearing lode present. The fact that no significant zinc anomalies are present in the eastern portion of Fig. 23 makes this area worthy of investigation in an attempt to locate the source of this dispersion pattern. However, to the north of the No. 3 vein the high zinc values could be due to zinc being taken up by the vegetation since the tree-line begins a short distance downslope from this occurrence. Furthermore, below the tree-line very boggy conditions are present. Thus, the combination of bog and vegetation may have given rise to a false anomaly which bears no relationship to the lead-silver ore mineralization or to zinc bearing lodes.

SUMMARY

In this area the results of the orientation survey indicate that copper and zinc tend to be displaced by chemical means. In addition, zinc tends to be taken up by vegetation, which may produce a false anomaly. On the other hand, mechanical or physical factors have produced the dispersion of silver and lead anomalies by soil creep and solifluction. Thus, with the exception of zinc, the high values for copper, lead and silver terminate near the source of mineralization.

The orientation survey has revealed that lead is the most suitable element for geochemical prospecting by soil sampling in the Sixtymile River area.

The lead-silver ore mineralization is present in vein faults which strike in a general direction towards N 50° E. These vein faults usually appear as linear features which can be easily traced along strike for distances up to 5,000 feet. Therefore, the initial reconnaissance geochemical soil sampling should be conducted along traverses perpendicular to these lineaments. In this study, anomalous

lead values were found to occur in a zone from 80 to 700 feet wide in the vicinity of the ore veins. Mechanical dispersion due to soil creep and solifluction is mainly responsible for this variation. On this basis, even when lineaments are not evident, geochemical soil sampling on a reconnaissance basis could be carried out along traverses spaced 1,000 feet apart, striking N 40° W. The sample spacing interval along these traverses would depend on the topography. For slopes between 5° and 10°, the sample spacing interval could be 300 feet; however, for slopes greater than 16°, the sample spacing interval should be reduced to 75 feet (see Fig. 24). Any anomalous lead values encountered along these traverses could be followed up with a detailed soil sampling pattern.

Approximately one-half pound of soil is collected at each sample point between 1 to 1.5 feet below the surface. The sample is dried, sieved, and the fraction less than -120 mesh leached in a 5% ammonium citrate -6N. HCl solution. The filtrate from the leach is evaporated to dryness, treated in concentrated nitric acid, evaporated again to dryness, and the residue taken up in a measured volume of dilute nitric acid. This solution is run on the atomic absorption spectrophotometer. This procedure may be shortened in the interests of speed and economy by leaching smaller samples in a test tube, diluting to a given volume, and testing the supernatant liquid directly. Development of a simpler and quicker method was not undertaken as part of this thesis. A cold leach method with indicator paper testing might be possible as field method.

MINERALOGY

INTRODUCTION

Wall rock alteration involves mineralogical and chemical changes resulting from circulating solutions within the host rocks of ore bodies. These changes often contribute to the evaluation of the processes of ore deposition by inferences concerning the chemical and physical environments where ore accumulations take place. Or, they facilitate the recognition of changes within ore-depositing processes over periods of time at specific sites, and the changes taking place within a given increment of an ore-forming solution as it migrates through the system (Meyer and Hemley, 1967). Thus, environments of ore deposition are interpretable in part from the assemblages of wall-rock alteration minerals. Attention must also be focussed on ores which are epigenetic with respect to the immediate wall rocks surrounding them.

WALL ROCK ALTERATION

At each of the three occurrences of lead-silver ore the effects of hydrothermal solutions and meteoric waters is evident near the mineralized faults. The passage of these solutions has in some cases leached out the soluble compounds leaving the rocks soft and friable, especially near the mineralized faults. Near the mineralized faults, the rocks are well jointed and the joint faces are stained with limonite and goethite as a result of the passage of meteoric water. This zone of staining adjacent to the mineralized faults has been found to extend for distances of a

100 feet or more (Fig. 10 and Fig. 27). In addition to the effects of meteoric waters, sericitic alteration is most abundant near both the mineralized and the unmineralized faults. This sericitization is in part attributed to the chemical and mineralogical changes brought about by the passage of hydrothermal solutions through these faults. Within the faults the occurrence of limonite and illite is common.

The source of illite within these faults could be due to several factors. Illite can occur through the disintegration of the muscovite of the surrounding gneissic rocks and recrystallize in a colloidal form (Deer, Howie, and Zussman, 1962, vol. 3). However, the most likely source of illite would be hydrothermal. Bonorino (1959) found that around metalliferous veins illite can occur either as the pure mineral, or as a component of a mixed-layer clay. The illite is assumed to derive its potassium from the breakdown of K-feldspar and occur within the inner zone of alteration. Experimental evidence suggests that for both sedimentary and hydrothermal occurrences, the formation of illite is generally favoured by alkaline conditions and by high concentrations of aluminum and potassium. Nevertheless, Gruner (1939) has shown that micas and illites can form in acid environments as long as an excess of potassium is available.

Within the mineralized faults a sequence of limonite-illite-galena is observed. In many of the adjacent faults only the limonite-illite sequence has been observed. Figure 28 shows the occurrence of illite within one of these faults.

No. 1. VEIN		No. 2. VEIN		No. 3. VEIN	
	OVERBURDEN		OVERBURDEN		
	GALENA VEIN		GALENA VEIN		
		HIGHLY SERICITIZED FELDSPATHIC GNEISS			
		HIGHLY SERICITIZED FELDSPATHIC GNEISS WITH BLACK GOETHITE COATING ON JOINT FACES			
		HIGHLY SERICITIZED QUARTZ FELDSPAR AUGEN GNEISS			
		BLEACHED GNEISS, NO RECOGNIZABLE MICAS			
		ILLITE-GREYISH-BUFF COLOR			
		BLEACHED GNEISS, NO RECOGNIZABLE MICAS			
		REDISH ALTERED GNEISS			
		SERICITIZED QUARTZ FELDSPAR AUGEN GNEISS, WELL JOINTED WITH ABUNDANT GOLDFLUTE ON JOINT FACES			
		BETTER FOLIATED QUARTZ FELDSPAR MUSCOVITE GNEISS			
		HIGHLY ALTERED AND JOINTED QUARTZ FELDSPAR AUGEN GNEISS			
		LIMONITE AND ILLITE			
		HIGHLY ALTERED AND JOINTED FELDSPATHIC GNEISS WITH ABUNDANT GOETHITE ON JOINT FACES			
		WELL JOINTED QUARTZ FELDSPAR AUGEN GNEISS			
		WELL FOLIATED QUARTZ FELDSPAR BIOTITE MUSCOVITE AUGEN GNEISS			
		THIN GALENA, ANGLESITE, CERUSITE BOX-WORK STRUCTURE			
		WELL FOLIATED QUARTZ FELDSPAR BIOTITE MUSCOVITE AUGEN GNEISS			
		SCALES: 1" = 4 FEET			
		SCALES: 1" = 15 FEET			
		SCALES: 1" = 50 FEET			
					FIGURE 27. TYPICAL WALL-ROCK ALTERATION IN THE IMMEDIATE VICINITY OF THE THREE LEAD-SILVER ORE OCCURRENCES



Figure 28: Typical occurrence of illite within a fault zone near the No. 3 vein.

In the Keno Hill area, the clay minerals found within the fault zones are said to be kaolinite and montmorillonite (Boyle, 1965). Yet, in the Sixtymile area only illite is encountered within the fault zones. Figure 29 shows typical diffractometer traces of these illites. Three samples were taken; one from each of three different faults. The diffraction patterns were identical for all three samples indicating a 10 Å c-axis spacing and a non-expanding lattice. An examination of Fig. 29 shows four peaks, two of which are rather weak. Yet, these peaks retain the same 2θ position subsequent to glycolation, but all have a slightly smaller intensity. Heat treatment at 550° C. causes no shift in the lattice spacing but results in a slight increase in the peak intensities. None of the diffraction patterns show any reflections from montmorillonite, quartz, or kaolinite.

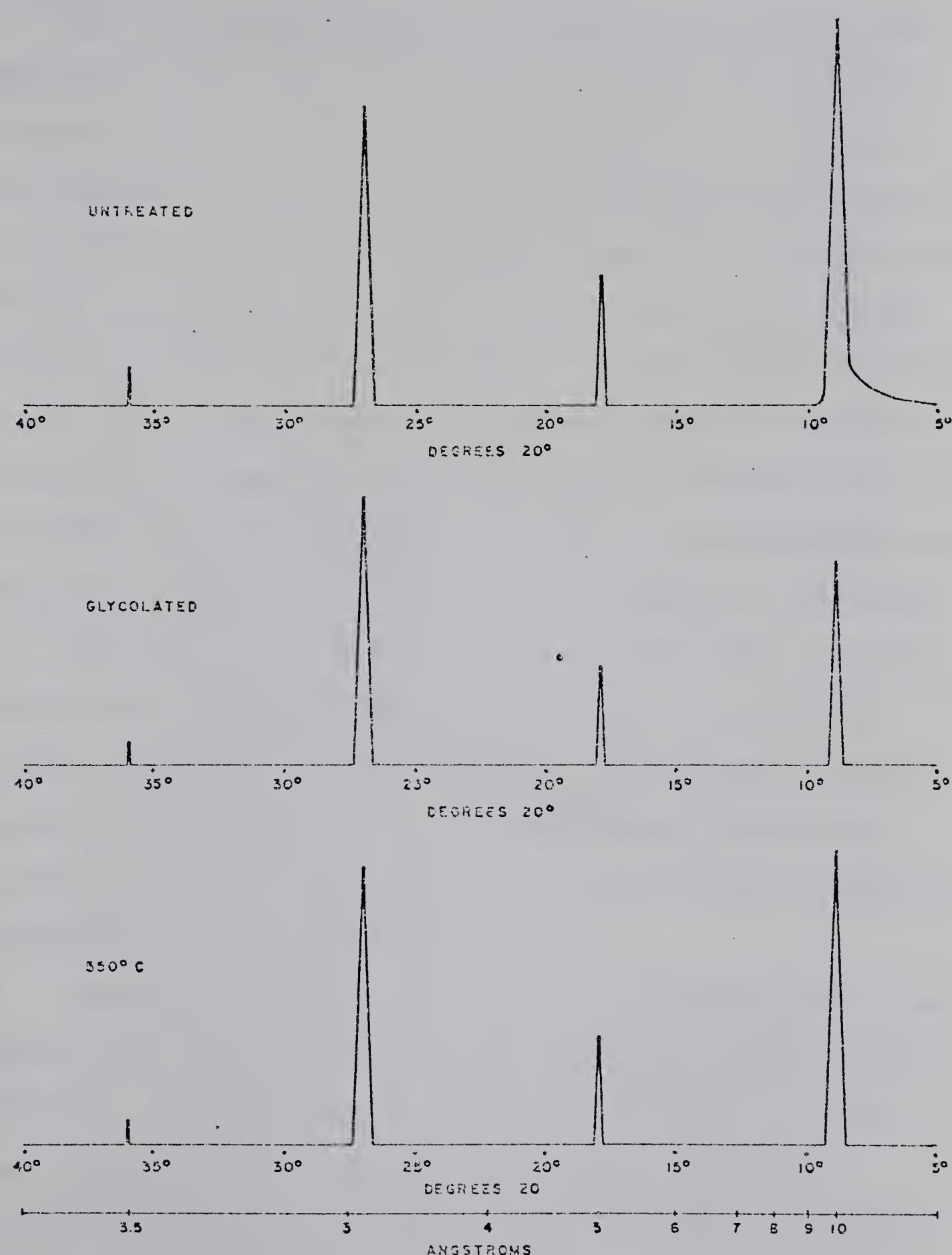


FIGURE 29. X-RAY DIFFRACTOMETER PATTERNS FOR ILLITE

MINERALIZATION

Ore bearing fluids change in composition as they migrate away from their source. The factors which will affect the composition of an ore bearing fluid are reactions with wall rocks, changes in pH, migration of fluids to regions of low temperatures and pressure, and the loss of heat to the surrounding country rock. These factors affect the stabilities of certain minerals within the ore bearing fluids, with the consequent deposition of specific phases at certain times. Thus, a general sequence of mineral deposits is established which does not necessarily depend upon depth or temperature, nor on the origin (Park and MacDiarmid). The origin of these deposits can be magmatic, pegmatitic, hydrothermal, pneumatolytic or metamorphic.

The works of Lindgren (1937), Edwards (1947, 1952), and Emmons (1936) have established certain mineral sequences in which the orders of mineral deposition are listed. Applying these classifications to the lead-silver ore occurrences in the Sixtymile area (Table 3, p. 36), the deposits would represent the latter stages of deposition by hydrothermal fluids.

The late hydrothermal ore deposits of the Sixtymile River area appear to be correlatable to a certain extent with those found at Keno Hill. Boyle (1965) states that in the Keno Hill area there were 3 major periods of hypogene mineralization. The first period is marked by the development of numerous quartz stringers, lenses and irregular bodies in fractures, joint, small faults, and contorted zones in various sedimentary rocks. The

second period of mineralization is represented by quartz-pyrite-arsenopyrite lenses in northeast striking faults, and the third period is represented by economic siderite lodes containing sphalerite, galena, pyrite, chalcopyrite, and frieburgite.

The mineral assemblage found in the Sixtymile River area differs in several respects. Firstly, there is an apparent lack of zinc in the ores (Table 3). However, it is likely that zinc may be encountered with depth in the mineralized faults as this situation is often found at Keno Hill. The second major difference is the lack of siderite bearing lodes. Since siderite has a limited stability field between pH 6 and 7.5, slightly acidic or alkaline conditions would cause siderite ($FeCO_3$) to be converted to an iron oxide (Garrels and Christ, 1965). Thirdly, apparently no cerussite is found in association with the anglesite. The reason for this apparent lack of cerussite has been discussed previously on page 37.

ORE DESCRIPTION

In the main veins, where the minerals have not been subjected to later brecciation, galena occurs as coarsely crystalline masses showing a well defined cubic cleavage (Plate III, Fig. 2). However, in the off-shoots from the main mineralized zone the galena exhibits strong brecciation (Plate I, Fig. 5), and adopts a sheared or plumose appearance.

The oxidation of galena to anglesite is very common in the Sixtymile area; (Plate II, Fig. 1). The aforementioned plate shows the banded boxwork nature of the anglesite surrounding an

irregular remnant core of galena. A complete conversion of galena to anglesite is indicated in Fig. 2 (Plate II). The central portion of Fig. 1 (Plate III), and the lower right of Fig. 5 (Plate I) indicate the replacement of anglesite by a silicate boxwork having a very porous nature. These specimens show the weathered surface and part of the cleavage which was originally derived from the galena.

ELECTRON MICROPROBE ANALYSES

The electron probe analyses were performed using an A.R.L. "EMX" electron microprobe. The silver analysis was affected by the use of the Ag L alpha line and an ADP analysing crystal. The antimony analysis was performed using the Sb L alpha line and an EDT analysing crystal. The Cu L alpha line and a KAP analysing crystal were used for the copper analysis. None of the analytical results were corrected for interelement effects.

The origin of the four samples A, B, C, and D, and the results of the bulk chemical and electron microprobe analyses are given in Table 4. Samples A and B were taken near the centre of the galena vein (Plate III, Figures 2 and 3). Sample C was taken near the outer edge of the galena vein where most of the galena had been altered to anglesite (Plate III, Fig. 4). In this sample there is a 1/4" strip of galena with anglesite on either side. Specimen D consists of 1 to 2 mm relicts of galena in anglesite (Plate III, Fig. 5). Within the anglesite, especially marginal to the galena, small isolated patches of covellite and binnite are found.

Table 3 and Table 4 list the minor constituents present within the galena. The amount of substitution by these elements for lead

Table 4. Results of bulk chemical and electron microprobe analyses in percent.

Specimen	Vein	Ag		Cu		Pb		Sb	
		No.	Bulk Chem- ical %	Micro probe %	Bulk Chem- ical %	Micro probe %	Bulk Chem- ical %	Micro probe %	
A	1	0.215	0.105	0.02	0.144	84.6	0.154		
B	1	0.196	0.122	0.01	0.077	83.7	0.204		
C	1	0.220	0.085	trace	0.268	84.3	0.115		
D	3	0.198	0.0	0.08	0.05	83.6	0.092		
D (Covellite)			1.97		48.96		0.603		
D (Edge zone)			11.325		39.5		0.34		

is uncertain for many of them may be present in associated minerals (Deer, Howie and Zussman, 1962, vol. V). However, substitution for lead in galena is not believed to be extensive. The work of Fleischer (1955), quoted by the foregoing authors, indicates that arsenic, antimony and bismuth can occur in galena up to a maximum concentration of 1, 3 and 5 percent respectively. Some of the antimony is usually assumed to be present in tetrahedrite, and some of the arsenic present in arsено-pyrite. Both bismuth and silver can occur in solid solution in galena as $(Ag, Bi) S-PbS$, or as exsolved matildite (Ag_2BiS_2) . The silver (Ag^+) has an ionic radius of 1.26 \AA ; whereas, lead (Pb^{2+}) has an ionic radius of 1.20 \AA . Thus, the silver could be admitted into the galena lattice. On the other hand, bismuth has virtually the same radius as lead, but, unlike lead, bismuth

is trivalent and it would be captured into the galena lattice. In addition, silver might occur as inclusions of argentite or acanthite (Ag_2S), and other sulfides. Table 3 also shows a low but significant concentration of tin in the ores. The tin may be partly associated with the sulfosalt component.

The work of Nesterova (1958) lists analyses of many galenas (Deer, Howie, and Zussman, 1962, Vol. V). Nesterova concluded from these analyses that silver, bismuth, antimony, tin, and copper do not enter the crystal lattice but occur in microscopic inclusions of other minerals.

Deer, Howie, and Zussman (1962, Vol. V) mention that traces of nickel, molybdenum, platinum, and gold are very rare in galena, yet the chemical and spectrographic analyses have revealed that these elements are present in the bulk samples of the Sixtymile ore. In addition, it is noteworthy that the spectrographic analyses of the lead-silver ores have indicated the presence of aluminum, magnesium, tin, calcium, titanium, and manganese. At this time, it can only be inferred these elements are associated in the following manner: The calcium and aluminum are probably associated with silica in a feldspar; the tin may be associated with the binnite; and manganese may be present in the form of wad which attracts other elements such as copper and nickel. Some nickel may occur in the pyrite, and magnesium might be present in the form of brucite, since brucite is a typical mineral of low temperature hydrothermal veins (Berry and Mason, 1959). Finally, the titanium may occur as associated ilmenite.

CONCLUSION FROM THE ANALYSES

Bulk ore chemical analyses were run on hand picked microscopic specimens of galena. The results of these analyses are given in Table 4. In the first three specimens (A, B and C), large discrepancies are evident between the microprobe analyses and the chemical analyses. A source of error in the chemical analyses would be due to poor sampling; that is, the massive galena was contaminated with microscopic quantities of secondary oxidation minerals occurring in veinlets. Thus, the bulk chemical analyses would give higher silver and lower copper values. On the other hand, when the galena crystals were analyzed with the electron microprobe, a pure crystal could be selected and the true amount of silver and copper in solid solution within the galena could be determined.

The higher copper content of samples A, B, and C revealed by the microprobe analyses may be due, in part, to a lack of data correction for inter-element effects. Similarly, the lower silver content suggested by microprobe analyses infers that some Ag-rich tennantite + Ag-rich covellite was sampled in the bulk samples. Also, the lower silver values could be due, in part, to the lack of data corrections for inter-element effects.

Sample D is the most altered of the four samples. The electron microprobe analyses on the relict patches of galena within the altered sample indicate the complete absence of silver in comparison with the bulk chemical analyses, and very low copper. This would indicate that silver, copper and antimony are leached first from the galena, during supergene alteration. These minerals

would then form a sulphosalt capable of being stable at normal temperatures.

Within the zone of secondary enrichment in sample D, covellite intergrown with binnite was observed. The microprobe analysis has indicated that the copper content of this covellite is approximately 40%. Such a value is not in accordance with the theoretical copper content of covellite (i.e. 66.5%). This lower copper content could be due partially to the substitution of iron within the covellite, or to microscopic binnite, and partly to the lack of corrections for inter-element effects.

The microprobe analysis of the argentian tennantite (binnite) indicated 11.325% silver, 0.34% antimony, and 39.5% copper. The normal composition of binnite is 13.65% silver, 0.13% antimony, 35.73% copper, 17.18% arsenic, and 25.04% sulfur. From these results, a reasonably good correlation exists for silver, antimony, and copper between the composition of binnite and the microprobe analysis of the unknown mineral.

In conclusion, reference is made to Table 27 (Deer, Howie, and Zussman, 1962, Vol. V) for the purpose of comparing the analysis of the Sixtymile ores to the analyses in the aforementioned table. The analyses listed in Table 27 show the minor elements silver, copper, iron, arsenic, antimony, and silica in association with galena. In this text the copper is assumed present in inclusions of covellite, iron is assumed to be present in pyrrhotite, copper and iron are assumed to be present in covellite and chalcopyrite, silver is assumed present in argentite, and 0.04 arsenic is assumed to substitute for sulfur. The results from Tables 3 and 4 indicate that at least silver, copper, and antimony are present

in the galena from the Sixtymile River area.

In evaluating the results of the electron microprobe analyses, consideration must be taken of the fact that no corrections were made for inter-element effects for silver and copper. Tentatively then, the microprobe analyses indicated that there is less silver in the galena than in the secondary enriched zone; conversely, there is more copper in the galena than in the secondary enriched zone.

PLATE I
PHOTOMICROGRAPHS OF THIN SECTIONS

Figure

1. Porphyroblastic quartz plagioclase biotite muscovite granite gneiss; the biotite shows extensive alteration to chlorite. This is typical wall rock found in the vicinity of the No. 1 and No. 2 vein. (plain light 10X).
2. Quartz plagioclase biotite muscovite gneiss. The feldspar porphyroblasts exhibit a chequerboard twinning under crossed nicols. This is the typical wall rock found in the vicinity of the No. 3 vein (plain light, 10X).
3. Micro-granite (a highly sericitized porphyry) showing original feldspar crystals replaced by masses of fine sericite, some pyroxenes and amphiboles have been altered to fine-grained chlorite (plain light, 10X).
4. Pseudomorph of a pyroxene crystal which has been altered to a fine-grained chlorite (plain light, 25X).

PHOTOGRAPH OF AN ORE SPECIMEN

5. A sample of galena from a thin veinlet near the No. 1 vein. The specimen shows that stresses have been induced after the galena was emplaced; as indicated by the brecciated fragments on the left and in the central portion.

In the middle-right the galena has been replaced by anglesite, and towards the lower right the porous nature of the specimen shows the weathered surface and the cleavage boxwork derived from the galena.

PLATE I.

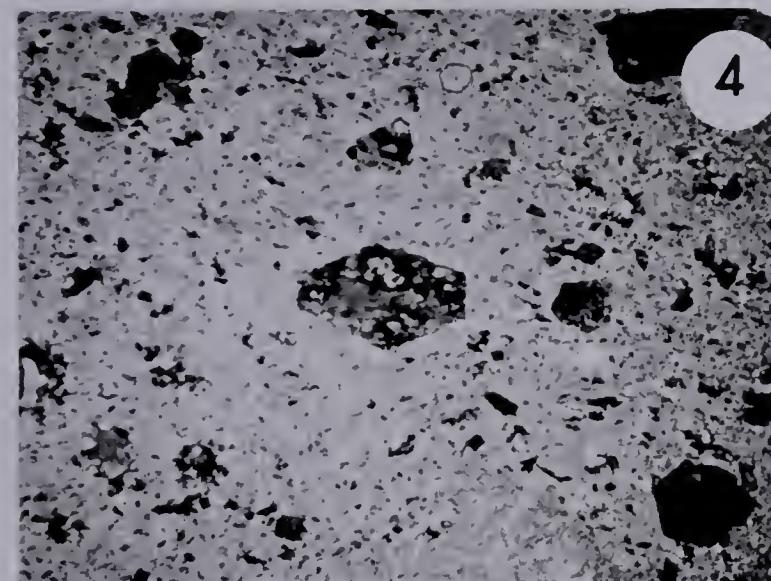
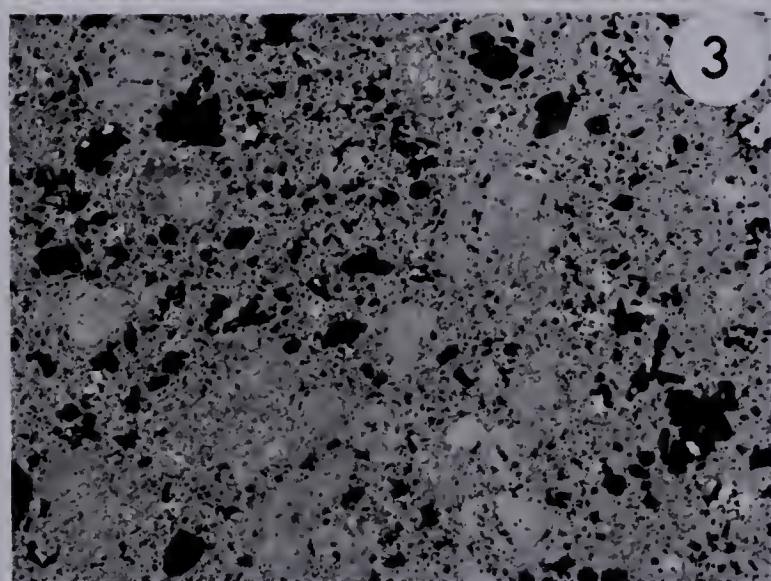
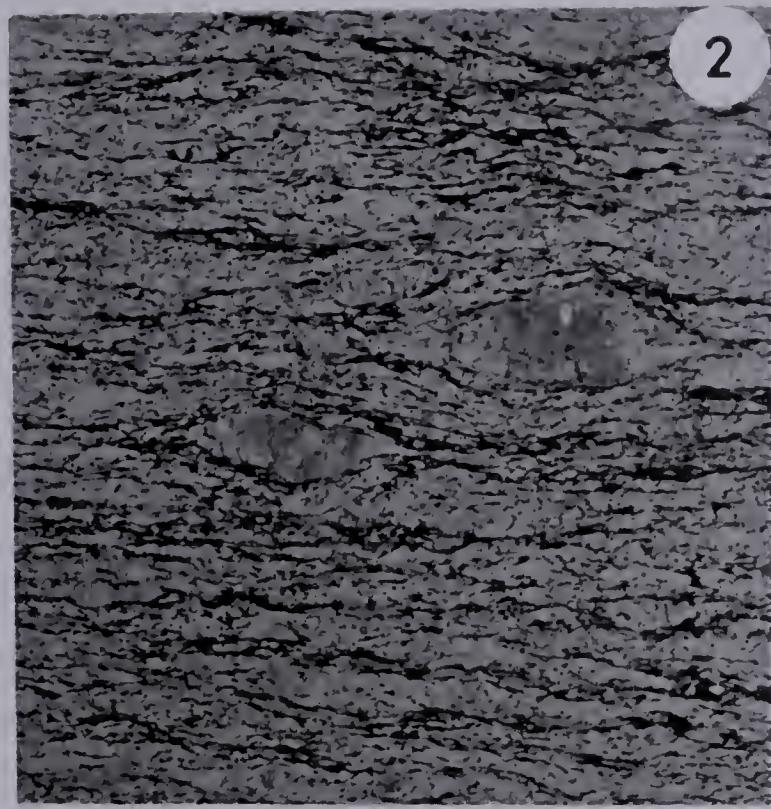
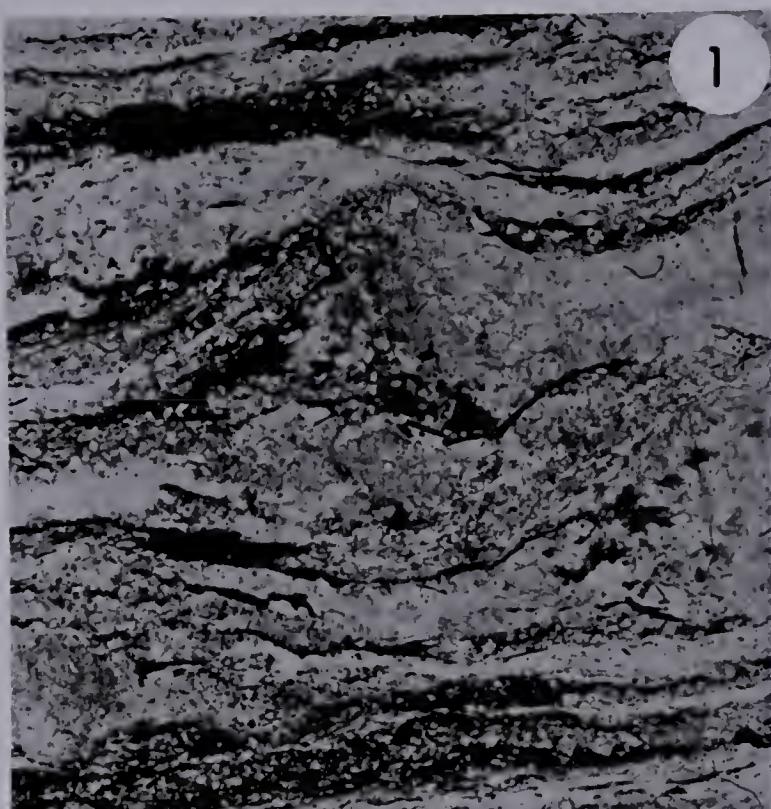


PLATE II
PHOTOGRAPHS OF ORE SPECIMENTS

Figure

1. A boxwork of anglesite surrounding residual galena, No. 3 vein.
2. Boxwork of anglesite entirely replacing galena, No. 1 vein.

PLATE II.



PLATE III
PHOTOGRAPH OF AN ORE SPECIMEN

Figure

1. Alteration of anglesite to a residual porous cleavage-boxwork. Note the large quartz crystals in the central portion (No. 3 vein).

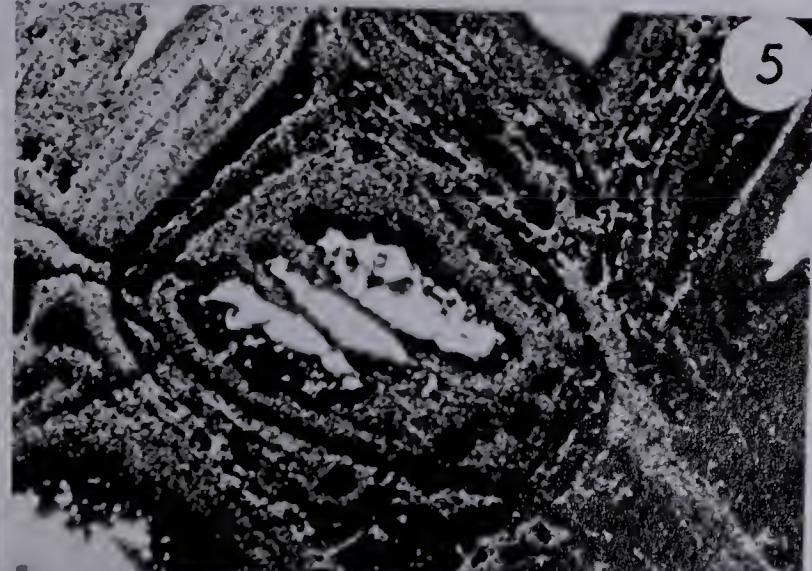
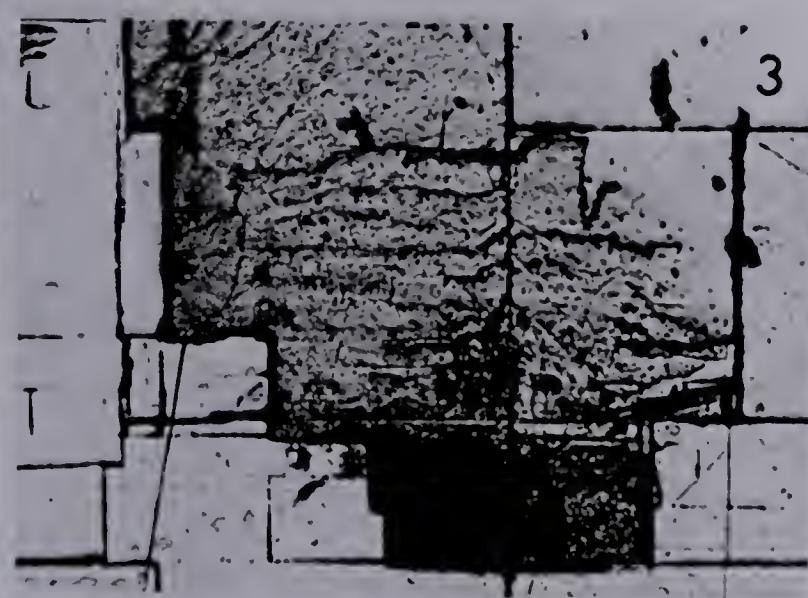
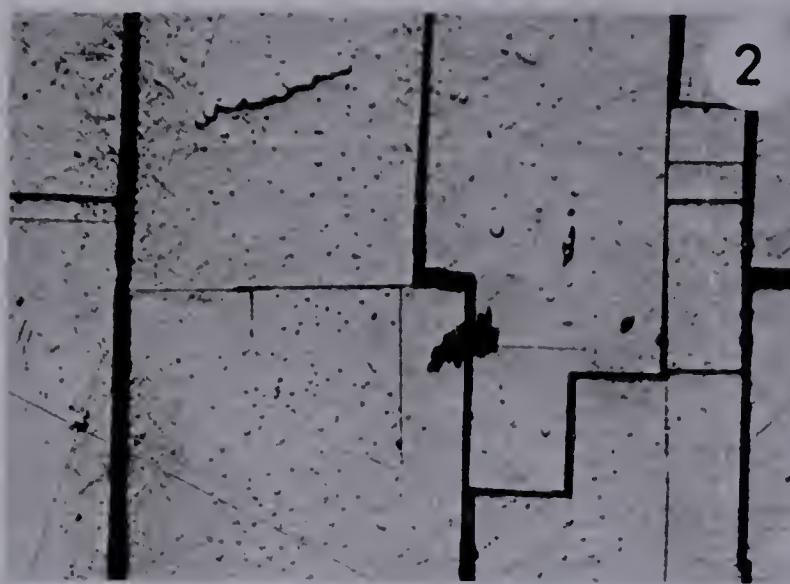
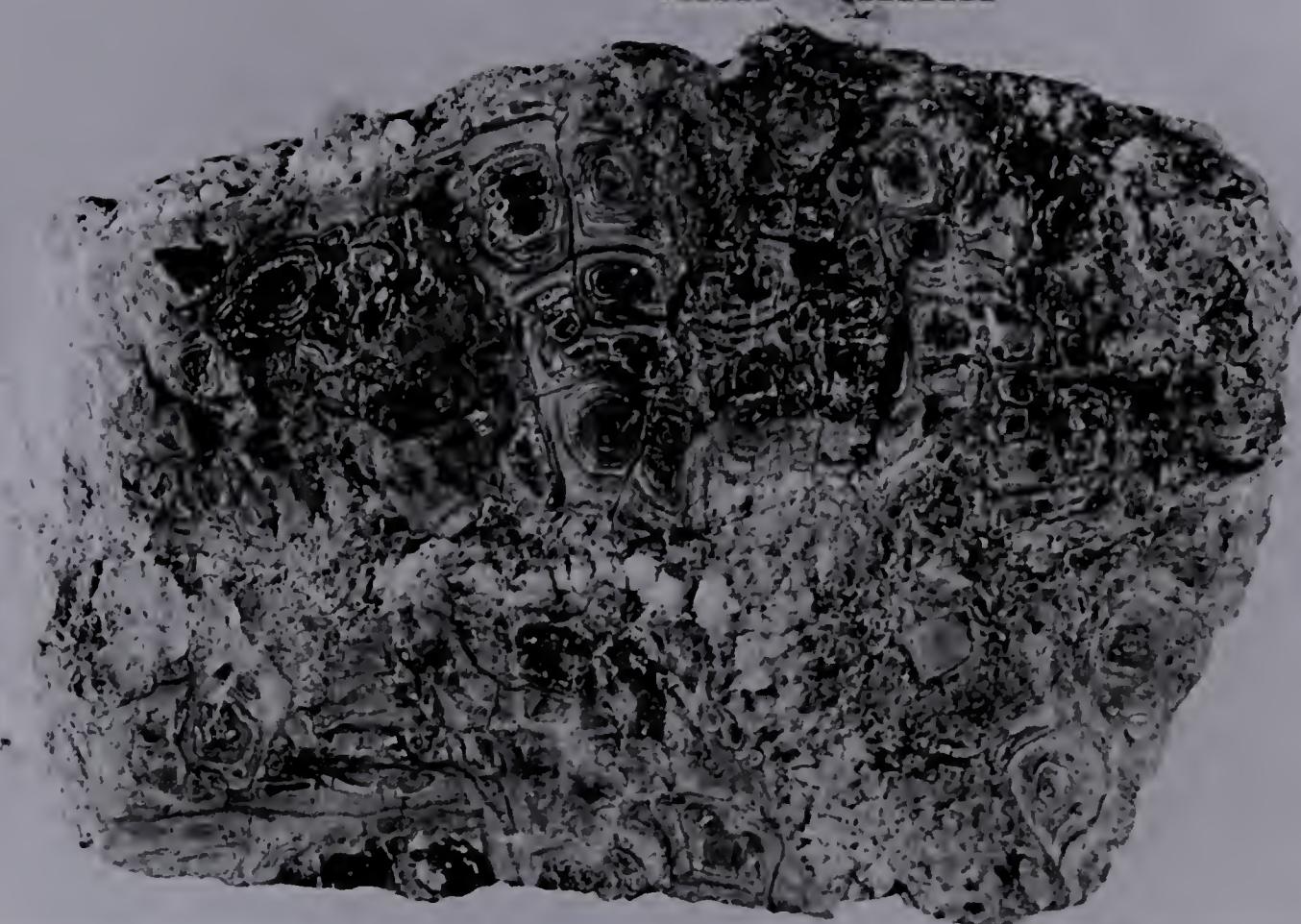
PHOTOMICROGRAPHS OF POLISHED SECTIONS

2. Galena from the No. 1 vein showing some alteration to anglesite between the cleavage faces (25X).
3. Galena (light grey) altering to anglesite (dark grey). The original crystal morphology of the galena crystals is still retained by the anglesite (No. 1 vein ~ 25X).
4. Outer edge of massive galena being altered to anglesite (No. 1 vein- 25X).
5. Relicts of galena (1 to 2 mm) in anglesite. Within the anglesite, marginal to the galena, are small isolated patches of covellite and binnite (25X).

PLATE III.

INCHES

1



REFERENCES

Berry, L. G., and Mason, Brian, 1959: Mineralogy, concepts, determinations; W. H. Freeman and Company, San Francisco and London, pp. 381-383.

Blanchard, Roland, 1968: Interpretation of leached outcrops; Nevada Bureau of mines, Bull. 66, pp. 45-64.

Bonorino, F. G., 1959: Hydrothermal alteration in the Front Range mineral belt, Colorado; Bull. Geol. Soc. Amer., Vol. 70, p. 53.

Brooks, A. H., 1906: The geography and geology of Alaska; U.S. Geol. Surv., Prof. Paper No. 45.

Boyle, R. W., 1965: Geology, geochemistry, and origin of the lead-zinc-silver deposits of the Keno Hill-Galena Hill area, Yukon Territory; Geol. Surv., Canada, Bull. 111, pp. 89-98, 113-221.

Boyle, R. W., and Cragg, C. Brian, 1957: Soil analyses as a method of geochemical prospecting in the Keno Hill-Galena Hill area, Yukon Territory; Geol. Surv., Canada, Bull. 39, pp. 23-26.

Cairnes, D. D., 1912: The Yukon-Alaska International Boundary; Geol. Surv., Canada, Mem. 57, pp. 38-58.

Cockfield, W. E., 1921: Sixtymile and Ladue rivers area Yukon; Geol. Surv., Canada, Mem. 123.

Deer, W. A., Howie, R. A., and Zussman, J., 1963: Rock forming minerals; Longmans, Green and Co. Ltd., London, Vol. 3, pp. 213 - 223.

_____, 1962: Rock forming minerals; Longmans and Green Co. Ltd., London, Vol. 5, pp. 180-185.

Edwards, A. B., 1947: Textures of the ore minerals; Melbourne, Australian Inst. Mining and Metallurgy.

_____, 1952: The ore minerals and their textures; Clarke Memorial Lecture, Roy, Soc. New South Wales Jour. and Proc., Vol. 85, pp. 26-46.

Emmons, W. H., 1936: Hypogene zoning in metalliferous lodes; 16th Internat. Geol. Cong. Rept., Vol. 1, pp. 417-432.

Fleischer, M., 1955 in Deer, W. A., Howie, R. A., and Zussman J., 1963 (ed.): Rock forming minerals; Longmans, Green and Co. Ltd., London, Vol. 5, p. 180.

Gabrielse, H., and Wheeler, J. O., 1961: Tectonic framework of southern Yukon and northwestern British Columbia; Geol. Surv., Canada, Paper 60-24, pp. 27-30.

Garrels, Robert, M., and Christ, Charles, L., 1965: Solutions, minerals, and equilibria; Harper & Row, Publishers New York, pp. 201-204, 233-238.

Gates, L. H., and Gryc. George, 1963: Structural and tectonic history of Alaska; Am. Assoc. Petroleum Geologists, Mem. 2, pp. 264-277.

Geological Survey of Canada, 1957: Map No. 1048A.

_____, 1962: Map No. 13-1962.

_____, 1963: Map No. 30-1963.

Green, L. H., and Roddick, J. A., 1962: Dawson, Larson creek, and Nash creek map areas, Yukon Territory; Geol. Surv., Canada, Paper 62-7, pp. 15-17.

Gruner, J. W., 1939: Formation and stability of muscovite in acid solution at elevated temperatures; Am. Min., Vol. 24, p. 624.

Gunning, H. C., 1957: Possible proterozoic occurrences in British Columbia, the Yukon, and Northwest Territories, pp. 178-182 in Gill, J. E., (ed): The Proterozoic in Canada; Rey, Soc. Can., Spec. Pub. No. 2

Hawkes, H. E., 1957: Principles of geochemical prospecting, U. S. Geol. Surv., Bull. 1000-F, pp. 225-230.

Hawkes, H. E., and Webb, J. S., 1962: Geochemistry in mineral exploration; Harper and Row, Publishers, New York and Evanston, pp. 10-22, 114-227.

Leech, G. B., Lowden, J. A., Stockwell, C. H., and Wannless, A. K., 1963: Age determinations and geological studies; Geol. Surv., Canada, Paper 63-17, pp. 51-54.

Lindgren, Waldemar, 1937: Succession of minerals and temperatures of formation in ore deposits of magmatic affiliation; Am. Inst. Mining Engineers Trans., Vol. 126, pp. 356-376.

Lowden, J. A., 1960: Age determinations by the Geological Survey of Canada, Report I isotopic ages; Geol. Surv., Canada, Paper 60-17, pp. 7-10

_____, 1960: Age determinations by the Geological Survey of Canada, Report 2 isotopic ages; Geol. Surv., Canada, Paper 61-17, pp. 17-20.

Mason, Brian, 1962: Principles of geochemistry, 3rd edition; John Wiley & Sons, Inc. New York, London, and Sydney, pp. 132-140.

Mertie, L. B. Jr., 1930: Geology of the Eagle-Circle district, Alaska; U. S. Geol. Surv., Bull, 816, pp. 265-274.

_____, 1937: The Yukon-Tanana region, Alaska; U. S. Geol. Surv., Bull. 872, pp. 46-75.

Meyer, Charles, and Hemley, Julian, J., 1967: Wall rock alteration in Geochemistry of hydrothermal ore deposits, Barnes, H. L. (ed.); Rinehart & Winston, Inc., New York, pp. 166-232.

Mitchell, R. L., 1955 in Principles of geochemistry, 3rd edition; John Wiley & Sons, Inc. New York, London, and Sydney, p. 24.

Molly, Martin, W., and Kerr, Paul, F., 1961: American Mineralogist, Vol. 46, May-June, pp. 583-605.

Park, Charles, F., Jr., and MacDiarmid, Roy, A., 1964: Ore deposits; W. H. Freeman and Company San Francisco and London, pp. 157-212, 268-308.

Perkin-Elmer Corp, 1968: Analytical methods for atomic absorption spectrophotometry.

Prindle, L. M., 1909: The Fortymile quadrangle, Yukon-Tanana region, Alaska; U. S. Geol. Surv. Bull. 375.

Spurr, J. E. 1898: Geology of the Yukon gold district, Alaska; U. S. Geol. Surv., 18th Ann, Rept., pt. III, pp. 260, 262, 263.

Stockwell, C. H., 1963: Geology and economic minerals of Canada; Can. Geol. Surv., Econ. Geol. Series No. 1.

United States Geological Survey, 1964: Mineral and water resources of Alaska; pp. 30-41, Fig.'s 7, 8, and 9.

Wanless, R. K., Stevens R. D., Lachance, G. R., and Rimaite, J. Y. H., 1965: Age determinations and geologic studies, K-Ar isotopic ages, Report 6; Geol. Surv., Canada, Paper 65-17, pp. 23-25.

Wasserberg, G. J., Eberlein, G. D., and Lanphere, M. A., 1963: Age of the Birch Creek schist and some batholithic intrusions in Alaska (abs.); Geol. Soc. America, Spec. Paper 73, p. 258.

Wheeler, J. O., 1961: Whitehorse map-area, Yukon Territory; Geol. Surv., Canada, Mem. 312, pp. 51-70.

Troll, Carl, 1958: Structure soils, solifluction, and frost climates of the earth; translation 43, U. S. Army snow ice and permafrost research establishment, Corps of Engineers, Wilmette, Illinois, pp. 59-78.

APPENDIX A

SAMPLE PREPARATION AND PREPARATION OF STANDARDS

SAMPLE PREPARATION

Figure 30 shows the two methods of sample preparation for analysis.

PREPARATION OF STANDARD SOLUTIONS

In the preparation of standard solutions, salts of lead, copper and zinc were dissolved in dilute nitric acid. The silver standard was prepared by dissolving silver nitrate in water and standardizing with sodium chloride.

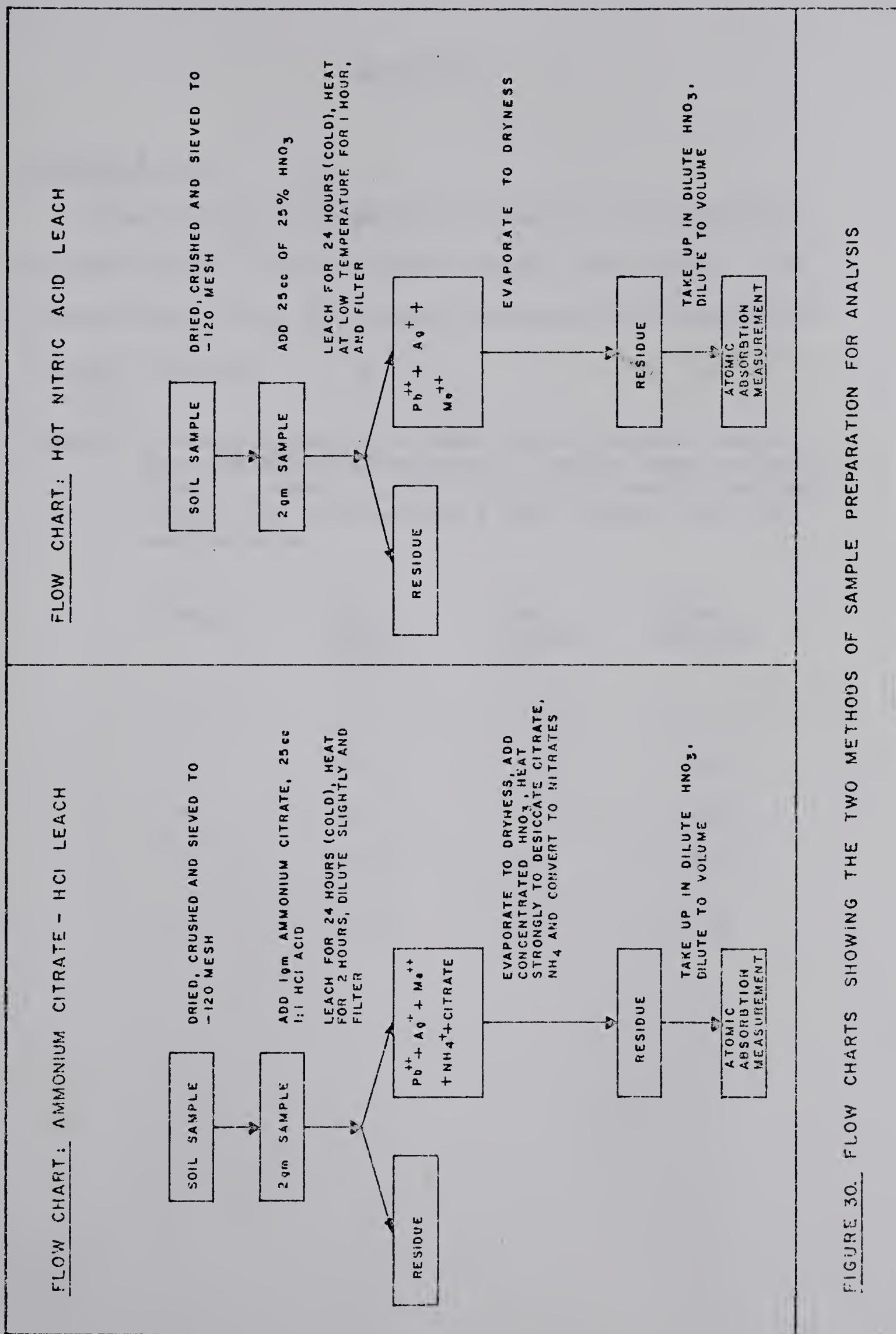


FIGURE 30. FLOW CHARTS SHOWING THE TWO METHODS OF SAMPLE PREPARATION FOR ANALYSIS

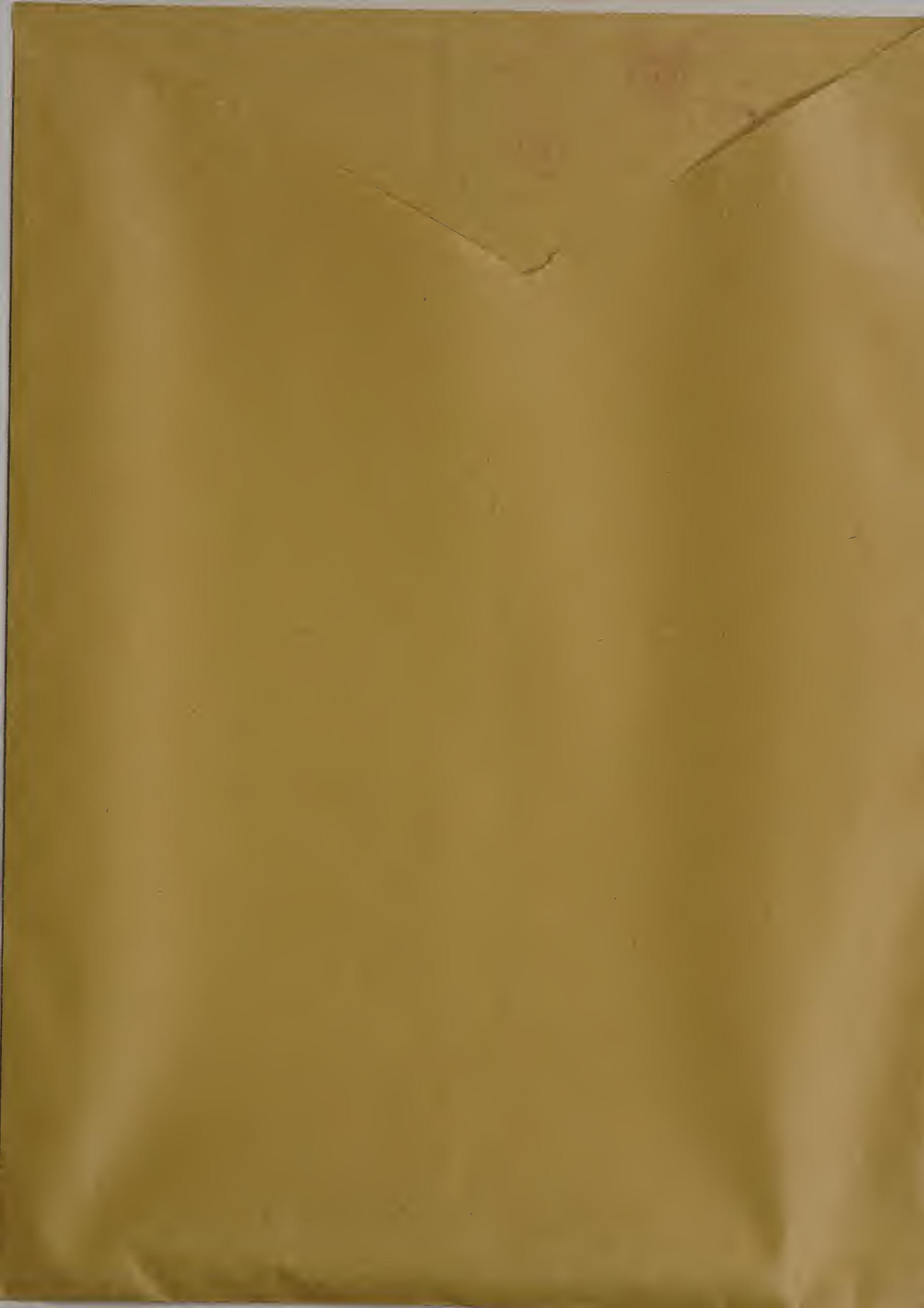
APPENDIX B

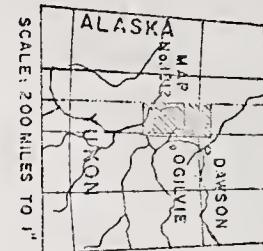
INSTRUMENT DATA

A Model 290 Perkin-Elmer Atomic Absorption Spectrophotometer was used for the analyses of silver, copper, lead and zinc. The following table gives the instrument setting for the analysis of the four elements.

Table 5. Instrument data for a Model 290 Perkin-Elmer Atomic Absorption Spectrophotometer. For the copper analysis a multi-element lamp (Cu, Cr, Co, Mn, and Ni) was used, and for the lead analysis a high intensity lead lamp was employed.

Element	Select Element Setting	Lamp Current mA	Flame Setting
Ag	286	4	13.62
Cu	280	7	13.60
Pb	206.5	15	13.62
Zn	84.6	12	14.00

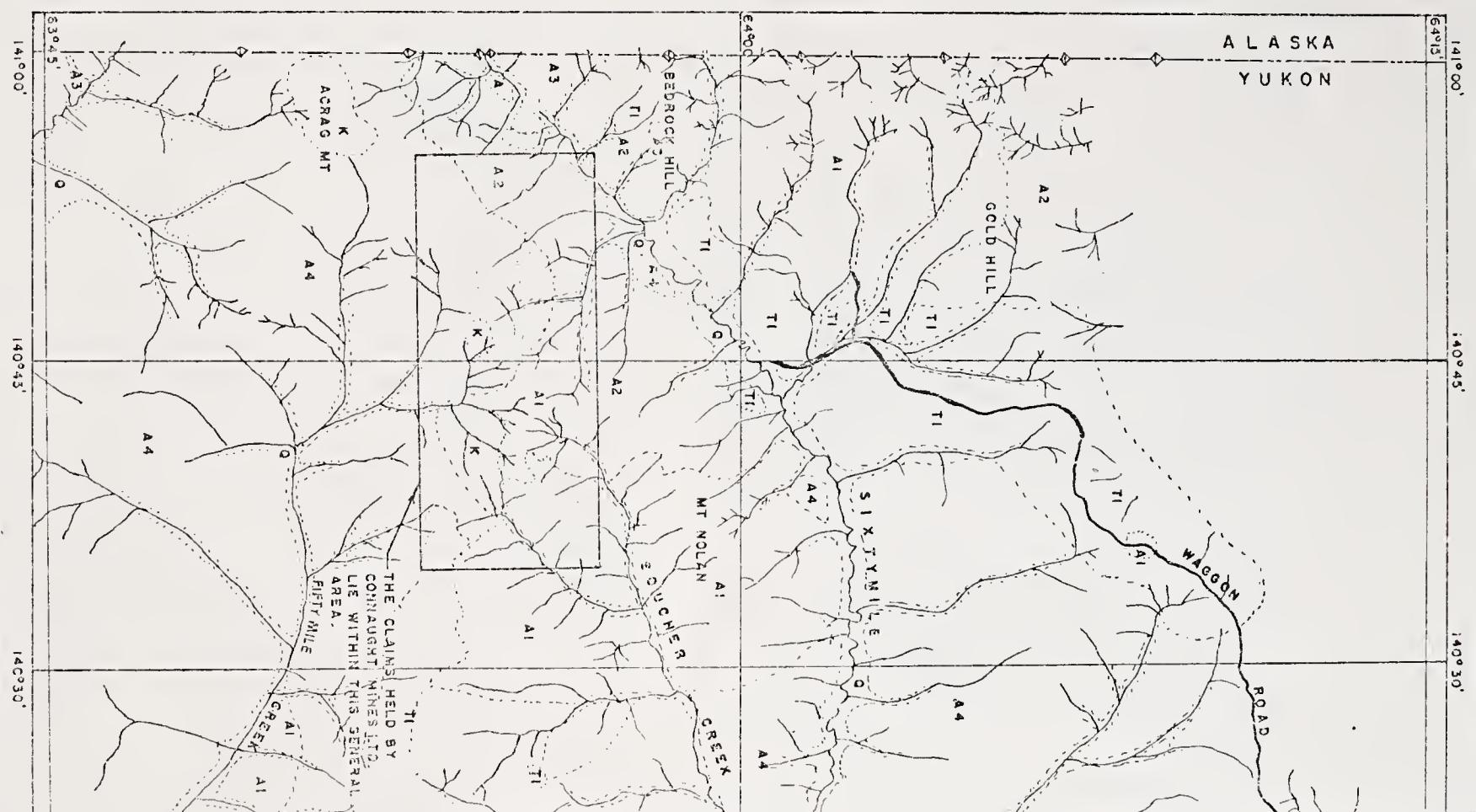




KEY MAP

LEGEND

C	SUPERFICIAL DEPOSITS (GRAVEL, SAND, SILT, MUCK, VOLCANIC ASH, AND GROUND ICE)
T2	RHYOLITE, QUARTZ, PORPHYRY, GRANITE, PORPHYRY, WITH ASSOCIATED TUFFS AND BRECCIAS
T1	NEWER VOLCANICS, WITH SOME SEDIMENTS (ANDESTITE AND DIABASES, ASSOCIATED WITH SANDSTONES, SHALES, AND CONGLOMERATES)
R	GRANITIC INTRUSIVES (GRANITES AND ALLIED PLUTONIC ROCKS)
K-C	OLDER VOLCANICS (ANDESTITE AND DIABASE)
A4	AMPHIBOLITE SCHIST (CHIEFLY GRANITE SCHIST AND ALLIED ROCKS)
A2	KLONDIKE SCHISTS (?) (SERICITE AND CHLORITE SERIES)
A1	NASINA-SERIES (QUARTZITE, QUARTZ, MICA SCHISTS, MICA SCHIST, SHEARED CONGLOMERATE, GRAPHITE SCHIST AND CRYSTALLINE LIMESTONE)



APPROXIMATE MAGNETIC DECLINATION 34°30' EAST

SIXTY MILE AND LADUE RIVERS,
YUKON TERRITORY

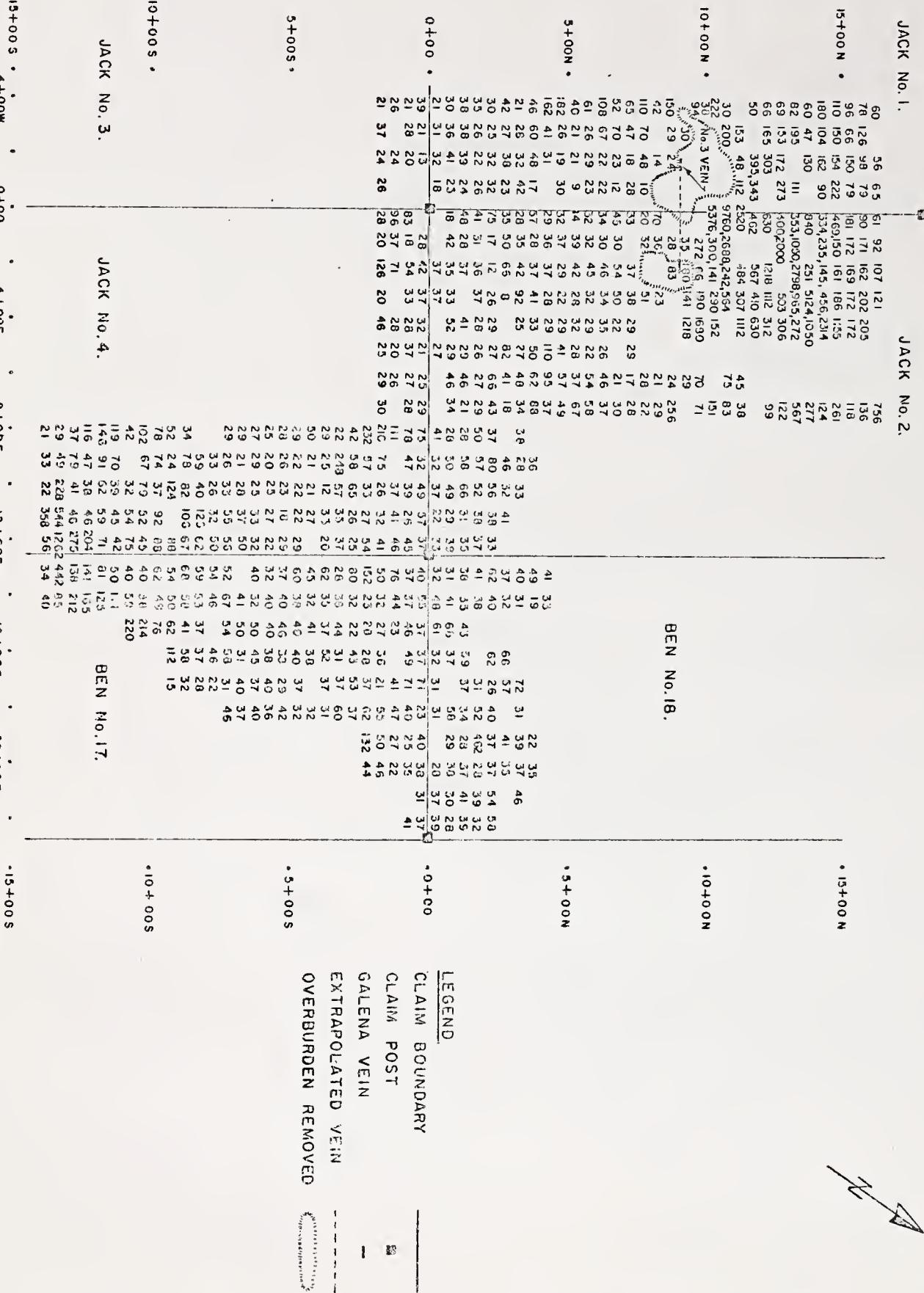
5 4 3 2 1 0 SCALE OF MILES 5

FIGURE 7.

SOURCES OF INFORMATION

GEOLGY BY W.E. COCKFIELD, 1917,
GEOGRAPHY FROM SURVEYS BY W.E. COCKFIELD, 1917,
AND FROM MAPS OF THE INTERNATIONAL BOUNDARY
COMMISSION AND THE TOPOGRAPHICAL SURVEYS BRANCH,
DEPARTMENT OF THE INTERIOR.

MAP COMPILATION BY W.E. COCKFIELD



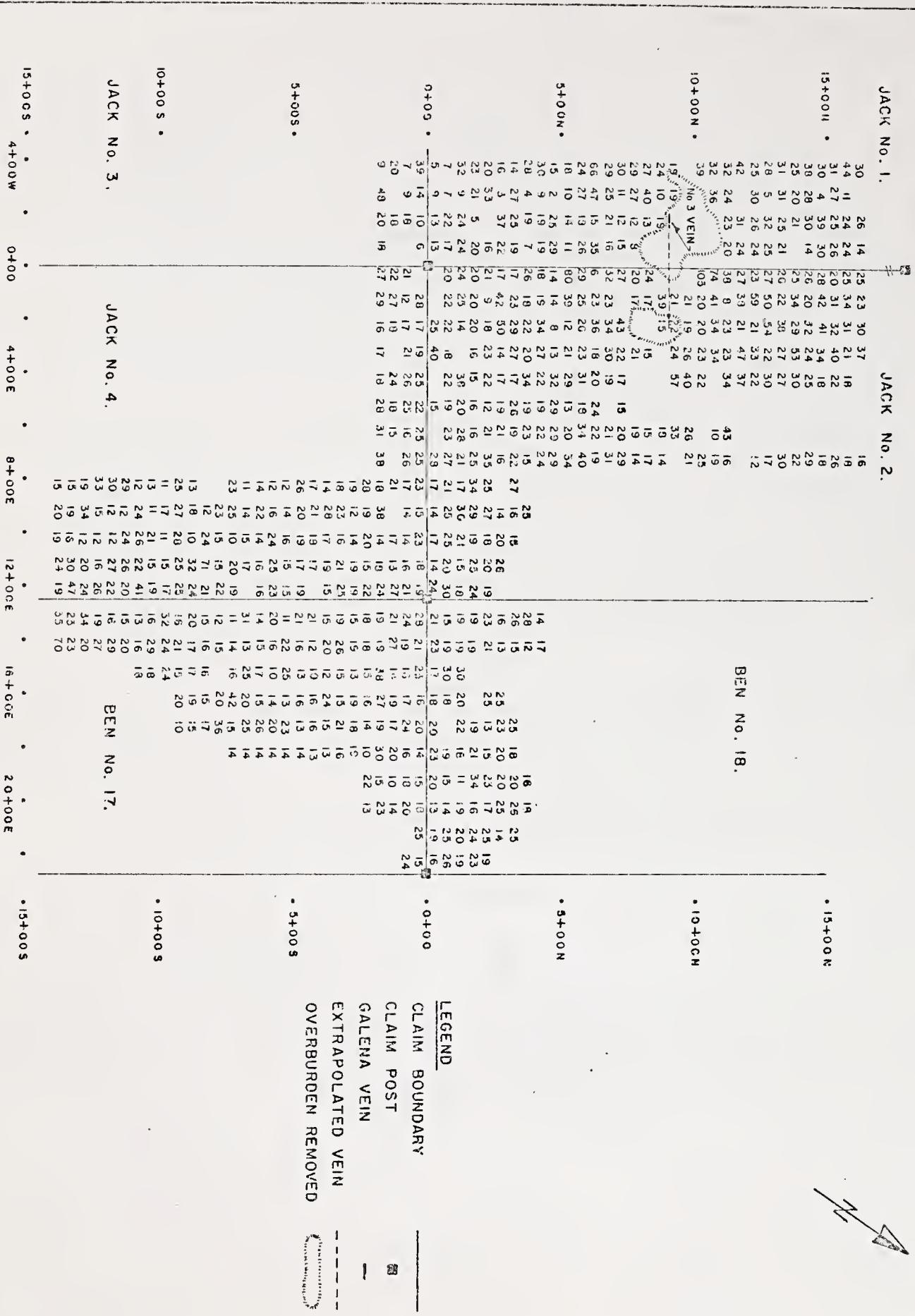


FIGURE 21A. PLOT OF COPPER CONTENT (μgm) IN THE RESIDUAL SOIL (ATOMIC ABSORPTION ANALYSIS)

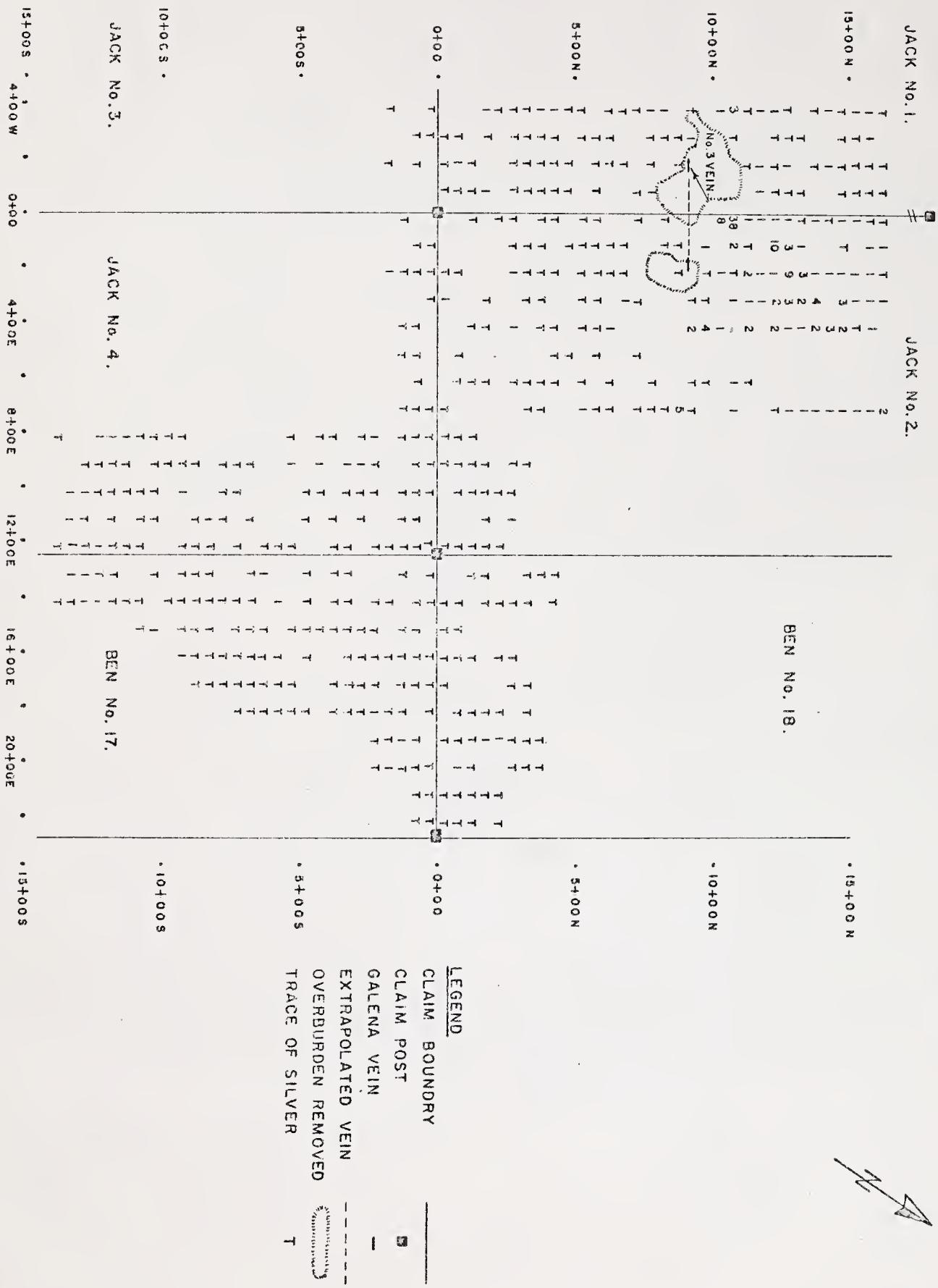


FIGURE 22. A. PLOT OF SILVER CONTENT (ppm) IN THE RESIDUAL SOIL (ATOMIC ABSORPTION ANALYSIS)

JACK No. 1.

JACK No. 2.

109 110 228 204106 80 90 380
 112 250 125 218 280339 135 98 135 106
 155 135 192 240 280 280 148 98 142 130
 15+00N • 300 360 144 347 380150 127 80 186 176
 238 160 154 63 432 912 127 204 135 367
 102 101 154 240 84 304 220 175 233
 178 64 240 224 185 144 240 123 105
 120 220 175 178 136 160 280 225 208 66
 112 225 246 48 334338 148 600 194 44
 110 188 75 196 324 200 150
 100 240 35 59 275127 300 60 135 32 377
 61 129 320105 148 92 27 38
 93 304 71 106 112 200 84
 No.3 VEIN • 80 63 184 150 60 52

64 68 111 113 86 75 52
 110 176 91 58 118 164 176
 255 174 1135 86 192 58 36 98
 192 240 104 37 111 114 41 80 66
 420 178 300 76 480 114 76 70 70 52 118
 350 770 94 108 456 247 316 166 73 83 66
 330 185 61 53 240 92 212 52 114 59 76 130
 96 73 59 108 156 95 92 28 76 60 309 76
 57 45 73 42 111 58 142 310 95 55 66 98
 5+00N • 74 63 122 79 92 344 103 32 264 534 55 44
 617 235 76 75 70 324 160 50 216 63 63 224
 94 124 73 25 353 89 103 63 176 135 89 127 76 63 52
 175 144 127 173 155 135 118 60 182 103 46 76 58 66 76 89 30 58 60
 264 71 89 127 456 272 286 324 28 95 95 135 111 55 73 63 55 70 66 76 58 52
 94 61 192 23 332 79 38 48 70 74 158 76 55 66 52 69 73 70 61 58 70 46 60 80
 80 96 298 190 224 83 135 73 50 34 03 83 98 92 63 56 50 70 73 55 80 90 46 60 44
 71 124 185 144 280324 106 46 254 111 106 103 83 60 46 66 63 56 76 80 80 41 63 58 50
 144 150 173 53 240156 89 86 103 176 70 118 83 135 60 60 43 76 66 92 63 66 58 63 58 39
 0+00 • 118 136 62 820 160 130 176 146 80 76 34 76 57 63 66 66 63 63 55 73 60 63 80

69 88 49 59 62 114 70 146 34 27 194 70 50 55 83 52 63 73 60 60 70 44 58 41 63 63
 57 69 154 154 152 83 95 16 135 114 03 92 123 76 56 44 63 46 58 65 70 86 55 53 44 111
 112 73 224 52 55 103 73 164 89 54 52 86 60 63 76 52 35 70 63 52 50
 116 71 243 62 130 52 76 53 36 51 38 70 70 57 44 42 66 57 63 62 66 43 95 66 70

123 46 73 83 60 98 60 35 58 60 92 50 60
 130 92 44 50 32 164 55 52 55 83 60
 58 46 52 76 52 55 55 63 55 52 66
 73 36 20 80 41 41 50 55 55 52 50
 76 73 52 52 76 52 60 45 58 55
 118 34 58 50 41 66 60 66 76 63 55
 38 41 38 45 50 70 49 66 49 66
 20 37 24 32 40 57 58 72 70 53 50
 32 54 20 24 36 73 60 95 52 55 52
 38 45 32 58 70 56 63 75 95 63 63
 24 41 27 63 62 86 83 86 86 50
 52 32 52 46 123 73 83 63
 58 34 103 60 106 95 63 58 52
 52 41 36 83 63 70 76 63 75 50
 36 377 127 103 35 83 86 66 86 37
 83 75 86 66 103 71 73 72
 92 60 34 52 86 92 58 95
 318 63 36 58 89 66 86 89
 76 60 127 41 86 58 92

10+00S • 70 36 44 76 83 70 86
 63 46 38 72 103 83 66
 38 158 46 60 190 86 70
 50 60 76 148,150 135 73
 55 57 44 86 63 54 63

JACK No. 3. JACK No. 4.

15+00S • 4+00W 0+00 4+00E 8+00E 12+00E 15+00E 20+00E 15+00S

BEN No. 18.

• 15+00N

• 10+00N

• 5+00N

• 0+00

• 5+00S

• 10+00S

• 15+00S

LEGEND

CLAIM BOUNDARY

—

CLAIM POST

■

GALENA VEIN

—

EXTRAPOLATED VEIN

OVERBURDEN REMOVED

○

FIGURE 23A. PLOT OF ZINC CONTENT (ppm) IN THE RESIDUAL SOIL (ATOMIC ABSORPTION ANALYSIS)

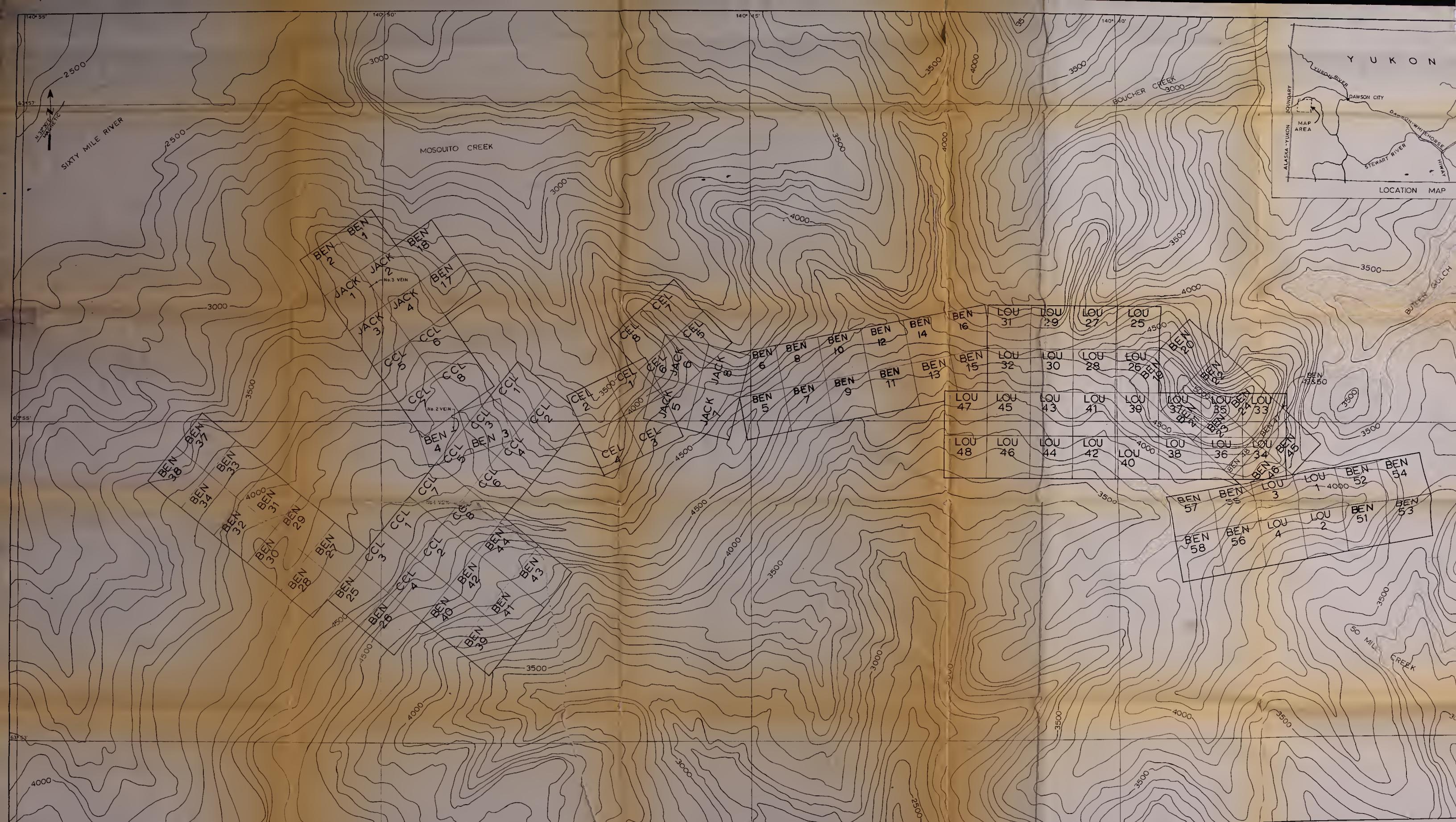


FIGURE 31.

MINERAL CLAIM BEN
123

1 CLAIM, 1500' x 1500' = 52.7 ACRES

CONNAUGHT MINES LIMITED
SIXTY MILE PROPERTY

NO ADEQUATE SURVEY DONE,
ERRORS MAY EXIST

DATE: OCT 24/68
DRAWN BY R. TOWSON

SCALE 4 INCHES = 1 MILE

CONNAUGHT MINES LIMITED

BEN

1 CLAIM, 1500' x 1500' = 52.7 ACRES

NC AOEQUATE SURVEY DONE,
ERRORS MAY EXIST

110

SIXTY MILE PROPERTY

NC AOEQUATE SURVEY DONE,
ERRORS MAY EXIST

DATE OCT. 24, 68

B29905